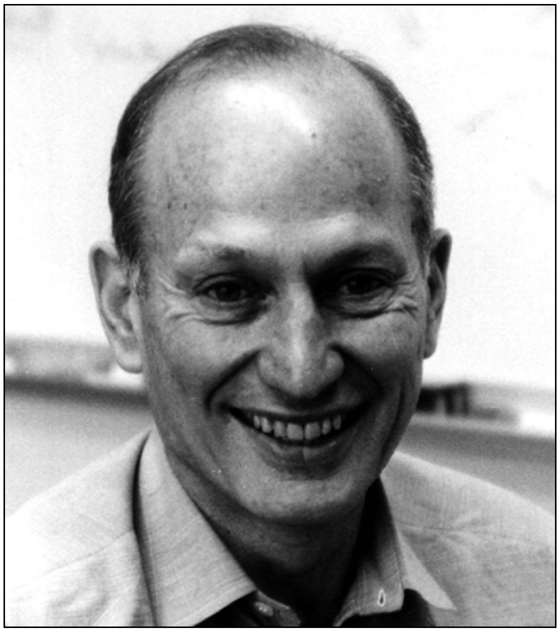

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AMNON YARIV
(Born 1930)

INTERVIEWED BY
SHIRLEY K. COHEN

November – December 1999

ARCHIVES
CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena, California

Subject area

Applied physics, electrical engineering

Abstract

Interview in three sessions in November and December 1999 with Amnon Yariv, Martin and Eileen Summerfield Professor of Applied Physics and Electrical Engineering in the Division of Engineering and Applied Science. Dr. Yariv received his BS (1954), MS (1956), and PhD (1958) from UC Berkeley.

He recalls his childhood in Tel Aviv in the British Mandate of Palestine, his parents' Polish background, and his early education, which included military training. In 1948, British occupation ends; he participates in the Israeli-Arab conflict; in 1950, leaves Israeli Army to attend the Technion, a technical university in Haifa.

Emigrates to U.S. in 1951; matriculates at San Mateo Junior College; transfers to Berkeley, studies electrical engineering (control theory); switches to radio engineering, under John Whinnery, for MS; enters new field of masers for PhD. In 1959, joins group at Bell Labs under James P. Gordon working on making the first laser. Visits T. H. Maiman at Hughes Research Laboratories after Maiman produces first laser using another approach. Leaves Bell Labs to

work on lasers for Watkins-Johnson. Joins Caltech September 1964 as associate professor of electrical engineering; sets up laboratory on semiconductor lasers and another on nonlinear optics. Contacts with Roy Gould; laser work of Nicholas George. Teaches course in solid-state physics and one in laser physics called Quantum Electronics. Publishes *Quantum Electronics* in 1967, first text in the field. Starts applied physics program in 1970, which includes Professors Thomas C. McGill, Roy Gould, Marc-Aurele Nicolet, William B. Bridges, Ahmed Zewail, William A. Goddard, Kerry Vahala, Harry Atwater, Paul Bellan, Noel Corngold, and Axel Scherer.

In late 1970s, invited by Tel Aviv University to join Sackler Institute of Advanced Studies. 1967 paper proposes optoelectronic integrated circuits using gallium arsenide crystals. Discusses ideas of Charles Kao on enabling fiberoptics with laser light; pioneer work at Corning on fiberoptics; work of his graduate student Kam Lau on modulation speeds; history of optical communication field. Starts fiberoptics company Ortel.

Discussion of the science of nonlinear optics and phase conjugate optics. Consultant for Arroyo Optics. Collaboration with Scherer on micro-optics; air force grant to study artificial periodic optical materials (photonic band-gap materials). Discussion of companies started by his former students. Concludes by commenting on his service in 1980s on committee formed to restructure LIGO and on his frequent visits to Japan and collaboration with Hitachi Labs.

Administrative information

Access

The interview is unrestricted.

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CALIFORNIA INSTITUTE OF TECHNOLOGY ARCHIVES

ORAL HISTORY PROJECT

INTERVIEW WITH AMNON YARIV

BY SHIRLEY K. COHEN

PASADENA, CALIFORNIA

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CALIFORNIA INSTITUTE OF TECHNOLOGY ARCHIVES

ORAL HISTORY PROJECT

Interview with Amnon Yariv **by Shirley K. Cohen**

Pasadena, California

Session 1	November 17, 1999
Session 2	November 24, 1999
Session 3	December 1, 1999

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COHEN: Perhaps we could start this interview by your telling a little bit about your family, where you were born and grew up.

YARIV: Well, I was born in Tel Aviv, Israel, in 1930. In 1930 Tel Aviv was a city of maybe 40,000 or 50,000 people. It adjoined Jaffa, the Arabic city. And mostly sand dunes at that time.

COHEN: How did your parents get there? Or were they originally from there?

YARIV: My parents came there separately; they weren't married yet. My father got there around 1925. He left Poland, left his family, lied on the visa application about his age—he made himself older than he was—and came to Israel. He was a so-called idealist, a Zionist. My mother came with her father and grandfather when she was about fourteen, at about the same time or maybe a few years earlier.

COHEN: And where did they come from?

YARIV: They also came from Poland. Both families were from Poland but from different towns. My mother came from Radom; my father came from Czestochowa. My mother's father was an industrialist and brought his cork factory with him to Israel. He bolted and crated it and moved it to Tel Aviv.

COHEN: He brought the whole factory with him?

YARIV: Yes. The factory was set up in what is today probably the bohemian section of Tel Aviv—Sheinkin Street. They made corks for wine bottles and cork plates for insulating cold-storage warehouses. Anyhow, my parents met in about 1928. My father, especially, was poor; he was working as a house painter. He finished a technical high school in Poland, came to Israel, and worked in construction as a painter for the first years. They met probably around 1928 and married soon afterward. I was born in 1930.

COHEN: So even though they came as Zionists, they weren't part of the kibbutz movement or anything?

YARIV: No. Not everybody went to a kibbutz, and they were not part of the kibbutz movement. My first impressions growing up were that a normal world was a world in which you had Arabs and religious Jews and secular Jews and a mishmash of languages and a hustle and bustle.

COHEN: And Tel Aviv was a safe city in those days.

YARIV: Yes, it was very safe. There were periods of disturbances involving shooting between the Jews and Arabs at different times. But Tel Aviv, because it was purely Jewish, was safe. Cities like Jerusalem and Haifa, which were mixed in population, were more problematic.

COHEN: Now, was the language of your parents already Hebrew?

YARIV: When they came to Israel, they of course spoke Polish and Yiddish, as did most of the Jews who came from Poland. At home they seldom spoke Polish; it was mostly Yiddish. And gradually as I grew up—partly because of me—they started speaking more and more Hebrew. I'd say that by the time I was a teenager, it was probably eighty percent Hebrew and twenty percent Yiddish. When they really needed to express themselves very precisely or tell a good story, it was in Yiddish. [Laughter]

COHEN: You have a younger brother?

YARIV: I have a brother who is six years younger than I am, yes.

COHEN: So you went to school then. What kind of schools were there at that time?

YARIV: In Israel, one went to school for six days, and school lasted from about eight o'clock in the morning until maybe one o'clock, so the days were not as long as they are here. The British had set up a system of schools, but anybody who went to those schools studied essentially in English, with Hebrew as a secondary language. So the Jews really, in some way, ruled themselves, through a self-government called the Jewish Agency—Ha-Sokhnut Ha-Yehudit. Among other things, it was a government within a government. So the Jewish population in a way was taxed twice. They were taxed by the British and taxed by their own internal government, which had no legal standing, really, but was very effective. Nobody objected. The result was that there was a whole network of schools run by the so-called Jewish government in Hebrew.

COHEN: And that didn't bother the British?

YARIV: No, they didn't care.

COHEN: So you could have gone to a school run by the British.

YARIV: Yes, I could have chosen to go to another school. Everybody had the choice of going to schools run by the British, the French, or the Germans. They all had their Alliance Française; there was a network of French schools in Israel. Many of my friends went to those schools. I maybe wish I had, because they became bilingual, completely. By the time they were fourteen or fifteen, they spoke French very well. I did not.

COHEN: Were there religious schools at that time?

YARIV: Part of the Jewish school network included religious schools, and I could have gone to one. People who came from religious homes did. I did not. And the schools, compared to American schools, were good schools.

COHEN: And everybody went?

YARIV: Everybody went—no exceptions. When I grew up, schools were mandatory in some sense until you were fourteen. High school was not.

COHEN: Where did you go to high school?

YARIV: Same city—two blocks from the beach of the sunny Mediterranean. [Laughter] That's where it started. My whole childhood, actually, was in the shadow of the beach, the sun.

COHEN: But as you got to be an older teenager, these were really exciting political times in Israel—or Palestine, as it was then.

YARIV: Yes, it was Palestine at the time. And I entered high school at fourteen—

COHEN: Now, high school had to be paid for?

YARIV: High school had to be paid for. That's a good question, because it wasn't mandatory and it probably would have been problematic for my parents to pay for my tuition in high school, because it was relatively a lot of money. But fortunately I got a scholarship. There were a small number of scholarships, and my elementary school was allotted one—and I wasn't the best student. [Laughter] A girl, Sarah Goldstein, whom I was madly in love with [laughter], got the fellowship, and I was really sad. And then a letter arrived—or maybe I was called: they had scraped one more fellowship together, and I got it. My parents later told me that they would have sent me to high school [anyway].

COHEN: They would have managed somehow.

YARIV: They would have managed somehow, scraping it together or whatever. But anyhow that was a great relief. So I went to high school. Tel Aviv at that time had about 100,000 people and was becoming a Pasadena-size town, with four or five high schools. Two of those schools were very good, very academic, and I went to one of those. After one year, which was standard, we had to choose one of three directions: mathematical, which meant mathematical-scientific; literary, which involved languages and philosophy; or business.

COHEN: Sounds as though this was patterned after the British schools.

YARIV: Yes. There was a common core; everybody had to pass the national exams, which are administered on the same day to all the high school graduates of Israel. If you pass them, you are entitled to go to a university. It's not as though if you went in one direction, like the literary, you could not study science. There was a common core that met the entrance requirement, let's say. But anyhow, I took the scientific-mathematical direction, and we got a lot of science. I didn't know how much until I came to Berkeley and they said, "You can skip the first year." [Laughter]

COHEN: So then the unrest, the war, must have broken out.

YARIV: In the meantime during that period, the world war was going on. And when the war was over, there was the underground war against the British, who withheld the refugees from Europe and kept them from arriving in Israel—you know, *à la* the movie *Exodus*.

COHEN: Yes. Well, we know that story.

YARIV: OK. So while I was in high school, we were already in a way inducted into the Israeli pre-army training. That's everybody in high school. We belonged to units. You belonged to either the Haganah, which was what they called the majority underground army, or some of my friends who were more ideological or who maybe had stronger opinions would belong to the Irgun or the Stern Gang, which were more extremist.

COHEN: So all this was already organized in high school?

YARIV: Yes. We had military training in high school. We would go on long trips into the countryside for three or four days. We would train with arms and reconnoiter and get in shape.

COHEN: Girls, too? Was it coed?

YARIV: Girls, too, yes. It was completely coed. Actually, it was exciting. [Laughter]

COHEN: [Laughter] Well, of course, for a teenager.

YARIV: Teenagers, yes. For instance, we would carry arms from one hiding place to another.

COHEN: So you did serious things, actually.

YARIV: It was serious, yes. I was chased once, for instance. At night we would put placards on walls—you know, various statements against the British or protesting this or that. And we would go with a pail of glue and a little brush and brush it on the wall and put up the placard and go on. Of course, that was an illegal activity. On one of those occasions, I was spotted by a British armored vehicle and they chased me. [Laughter] I had to jump a few fences. But at the same time, you went to school, played basketball, and went to the beach. Life went on.

COHEN: Life was normal, except that you did these other things also.

YARIV: That's right. As far as I knew, everybody in the rest of the world did that. [Laughter]

COHEN: So in some sense they were really getting you guys ready to fight.

YARIV: Yes, but we didn't, as teenagers, know how serious it was. You know, it was like a game.

COHEN: Now, your parents were aware of all this?

YARIV: Oh, yes. I'm not sure that I necessarily shared all the details with them, but they were aware of what was going on. Really, there was an amazing degree of unity. [Israel] was like one small family. The total number of Jews in Israel at that time, in 1948, was about 700,000.

COHEN: At that time, weren't there fights between religious Jews and nonreligious Jews?

YARIV: No, there were not. The religious have become very—what would you call it?—self-assertive now, very demanding. They are aware of their power, but they were not at that time. All this training for the eventual war was strictly done by the secular Jews, while the religious Jews were praying quietly.

COHEN: Nobody bothered them.

YARIV: And they didn't bother anyone. But they became militant much later, all of a sudden. Today, for instance, some of the elite army units are made up of religious young men, but not at that time.

COHEN: So it was just the secular folks.

YARIV: Yes. There were religious young men in the military army units, but there was no attempt to separate them or anything. They didn't come as a unit.

COHEN: So you finished your high school and you took your examination. Is that correct?

YARIV: Yes. I normally would have taken my examination in June, but that was 1948, and the British left Israel on the 15th of May.

COHEN: Just before your examination?

YARIV: They left Israel, and the date was announced in advance. After Israel was granted independence by the United Nations, the British stated that they would leave the country on May 15th, which was before my intended graduation date. And also the Arab countries that did not subscribe to the UN partition of Palestine had declared that on that date they would invade Israel. A war was going to take place, and we knew that. And we had been training for years, so our school year was terminated in April that year. We had very abbreviated exams.

COHEN: But there were exams.

YARIV: There were exams, but two months early. And on April 13th—I happen to remember, because it was my birthday—I had to report to duty. I was soldier 13654 [laughter] of the Israeli Army.

COHEN: So the army was already forming then.

YARIV: Yes. The British were leaving the country and we were training. You couldn't start training the day they left; you had to start training well in advance. I was assigned to the artillery, because I had graduated from high school and knew mathematics and trigonometry and so on. This was still in April, and the British were still in the country, conducting house-to-house searches, essentially making sure the Jews had no arms to fight the Arabs. So at night sometime in April, a bunch of us went to the Tel Aviv port and a freighter arrived from Italy with a load of onions. And at the bottom of the load of onions were guns. And we unloaded them at two o'clock in the morning. We put them on trucks. They were essentially anti-aircraft guns—20-millimeter Hispano-Suizas. [Laughter] And we loaded them on trucks and took them to an abandoned alcohol factory on the sand dunes in Herzliyya. I don't know if you know Herzliyya.

COHEN: Yes, I do.

YARIV: Right near the Sharon Hotel, a hundred yards or so south of it. Then a week or two later, maybe a hundred of us started training with those guns.

COHEN: And these were all high school graduates—I mean, eighteen years old?

YARIV: All of us were eighteen years old. Most of my high school class was there. And a few older people, like people who had served in the British Army or in the Russian Army, who had artillery experience. They were our trainers and officers. So by May 15th, when the British left Israel—basically the night before, we were sent to various locations and found ourselves on the front waiting for the action.

COHEN: For the Arabs?

YARIV: Waiting for the Arabs. My army unit was around Jerusalem. I saw action there, mostly with the Arab Legion, the Arab-trained army of Jordan.

COHEN: They were very highly trained, weren't they?

YARIV: Yes. It was essentially British-trained units and British equipment, and they gave us a lot of trouble. Many of my friends died in that period.

COHEN: So that was your high school graduation present. [Laughter]

YARIV: That's right. So that's high school.

COHEN: How long did these disturbances, or this war, last?

YARIV: The war probably lasted something like a year, with some cease-fires. I remember a cease-fire declared by the UN, monitored by Count Bernadotte, who was then killed by some Israeli extremists. The war started again. On and off, it was maybe for a year or so.

COHEN: So then, what did you do? You were with your unit?

YARIV: I was in this artillery unit. "Have gun, will travel." [Laughter]

COHEN: [Laughter] And you were lucky. I mean, you were OK.

YARIV: Yes. There was no organized artillery yet in the Israeli Army. The guns we had, the 20-millimeter Hispano-Suizas, could be mounted and dismounted very quickly—kind of an all-purpose gun. So at different times [we were in different places;] I was defending a station outside the Weizmann Institute, for instance. For a period of a week I was there, afraid that the Egyptians would bombard it. And then I was put on an American icebreaker, which had been converted to Israel's first warship. The American name was *The Northerner*. We mounted my 20-millimeter gun there and we became naval gunners. After a few weeks of that, and one naval engagement with the Egyptians [laughter], they were taken off and mounted on half-tracks. Do you know what half-tracks are?

COHEN: A kind of tractor?

YARIV: They are military vehicles which have two wheels in front and a track behind. That was the beginning of the Israeli armored force. [Laughter] So we moved our guns from one area to another.

COHEN: You took your guns off of the icebreaker and put them on these?

YARIV: That's right. Those were all the original guns that arrived there, under the onions. I think there were maybe fifty of them. They were the core, the beginning, of the Israeli artillery.

COHEN: You laugh about it, but it wasn't such a joke.

YARIV: No, not at that time. And then when the fighting and the war were essentially over, I was sent to the first artillery school of the Israeli Army to be an instructor.

COHEN: Already you were an authority.

YARIV: I was a maven.

COHEN: Maven, right. [Laughter]

YARIV: They felt we understood how the arms worked, so we organized the first training courses. Actually, I should give to the Israeli Military Archives a booklet of instructions for the gun we used.

COHEN: Your group wrote this?

YARIV: I wrote it.

COHEN: Oh, you wrote it—your first publication.

YARIV: I was given the job. It was my first publication. It's a manual for the deployment and use of the 20-millimeter Hispano-Suiza, with photographs. It shows the crew. There were four at various positions during the deployment of the gun.

COHEN: And you have this at home?

YARIV: I have it at home.

COHEN: Oh, you should give it to them. OK. So how long did this last?

YARIV: I was in the army for two years, almost to the day.

COHEN: And then things supposedly calmed down.

YARIV: They calmed down, the army started becoming regular, officers all of a sudden showed up with ranks, and they wanted to be saluted [laughter]—all of the things [we missed] at the beginning, you know.

COHEN: Nobody had time for it.

YARIV: There were no ranks at the beginning. So after half a year, the officers went back to headquarters and came back with ranks. [Laughter] Anyhow, my commanders wanted me to stay in the army, go to officer training and sign up for the regular army, but I knew that I wasn't cut out for the army, so I decided to go on to school.

COHEN: Your parents were still in Tel Aviv?

YARIV: Yes. I then planned to go to school at the Technion, which is a technical university in Haifa. It's about forty or fifty miles north of Tel Aviv. And I had already put down a payment on my first year's tuition. I was accepted in electrical engineering. And I had another half a year or so to go, so I started working.

COHEN: Before you started at the university.

YARIV: Yes. I made some money. And then one day in Tel Aviv on a bus, bus no. 2 [laughter], by accident I ran into an army friend who lived outside Tel Aviv. I asked him what he was doing in the city, and he said that he was on his way back from the American Consulate, where he had applied to go to school in the States. It sounded interesting. I said, "What? One can go to school in the States?" He said, "Yes. There is a small junior college"—I didn't know what "junior college" meant at that time—"south of San Francisco that allows Israelis and what's more it exempts them from tuition."

COHEN: It was just by chance that you met him on a bus?

YARIV: Chance. And I always tell this story, because it's about how little things can determine a life's outcome or course. Had I taken another bus five minutes later, or whatever, I wouldn't be here. [Laughter] I would be an electrical engineer in Israel. So you never know. Anyhow, he planted the idea that as long as I was going to school for four or five years, I might as well see the world. What I didn't tell you was that while I was in high school I was as much interested in languages as I was in science. And therefore I spent a lot of time on languages, reading a lot of English. I started reading novels in English very early—by tenth grade. I was in love with, among other writers, Jack London and his descriptions of San Francisco, Oakland, the fog, and bodysurfing the Pacific; *The Valley of the Moon*, his book that deals with the Sonoma valley.

Romantically, I had a vision of California. And there were a couple of movies with the Golden Gate and the fog. I decided I wanted to go to California.

COHEN: So you went to the consulate?

YARIV: So I applied to Berkeley, and Columbia because I had relatives in New York City, and San Mateo Junior College. [Laughter]

COHEN: And your parents were in agreement with this?

YARIV: Yes. I was accepted by all three, and I went to San Mateo Junior College, because they didn't have tuition there. Berkeley charged $200 or so.

COHEN: So San Mateo had no tuition for Israelis?

YARIV: No tuition—or maybe not for Israelis.

COHEN: But you still had to live.

YARIV: Yes. I had some money, which I saved working at odd jobs. I did odd jobs throughout college as an undergrad.

COHEN: So you left Israel—in 1950 was it?

YARIV: 1951. I left as a twenty-one-year-old and went to junior college. I stayed there one semester and then got a fellowship at Berkeley—meaning an exemption from tuition only. So I transferred to Berkeley.

COHEN: And there you stayed for—

YARIV: I stayed in Berkeley until 1959, about eight years. I studied electrical engineering as an undergrad, with an emphasis on control theory—you know, more traditional electrical engineering. I continued for my master's degree. I switched to radio engineering. And then I decided to do my PhD essentially in solid-state physics. I never really considered going to another school. I see students now weigh, or research very carefully, what graduate school to go to. I stayed at Berkeley, because it was convenient. [Laughter] I knew the professors. I didn't realize it then, but Berkeley turned out to have been a very good school, especially in the areas in which I was interested.

COHEN: Were there any people there that really influenced you?

YARIV: Oh, yes.

COHEN: Maybe you'd like to talk about them. Just another question: Did you go back to Israel to visit during this time? Because that would have been expensive.

YARIV: That would have been expensive, so for the first three years of my undergraduate studies I did not go to Israel.

COHEN: Did you know anybody when you came here?

YARIV: Nobody.

COHEN: Only Jack London.

YARIV: There was a colony of probably over a hundred Israeli students at Berkeley.

COHEN: Oh, so you had a family.

YARIV: And there was a Hillel. [A lack of] friends wasn't the problem. You know, Americans are very friendly, so my social life was varied and interesting.

COHEN: And your English was already quite good.

YARIV: Yes. There were no problems with English, so that was OK. As an undergrad, I had a professor of mechanical engineering as my advisor; his name was [James L.] Meriam. He was well known, because he had written a very good textbook. He was my advisor and he really was very conscientious about it; he took a great deal of interest. I had my periods of difficulty and all that. I came from a nonmechanical background. I never really fixed cars or—

COHEN: But you knew about guns. [Laughter]

YARIV: I knew about guns. [Laughter] I could assemble an Hispano-Suiza in the dark in two minutes [laughter], but that was not considered a big asset in Berkeley. So there were classes and courses at Berkeley—mechanical drawing and so on—and he kind of encouraged me to stick out those courses. And in graduate school my thesis advisor all those years was a professor by the name of John Whinnery, who is very well known.

COHEN: So you had the same advisor for your master's and your PhD?

YARIV: Yes. [Whinnery] was a pioneer in his field, which at the time had to do with more radio-type engineering. He was, at some point, the dean [of the College of Engineering] at Berkeley. Anyhow, he is one of those people—there's a term that denotes people as a category: let's call him "the virtuous among the people of the world." *Hassidi uu mot ha' olam.* Those are the people who are pure at heart. You probably can name a few of those people: people who don't have a bad thought in them, and not because they consciously try not to; they just don't have it. They do good because that's how they are. And he was one of them. I was lucky.

COHEN: So he guided you.

YARIV: Yes. He was my advisor and he was also very talented. And he had a sense of humor. He wrote children's poetry. He's still alive and he's doing OK. I was lucky to have been his student. That was a great influence. And he was part of the clique which was connected with the Hughes Research Labs and Bell Labs. As a matter of fact, Whinnery had written a book that is a classic in electromagnetic theory—Ramo and Whinnery [*Fields and Waves in Modern Radio*]. [Simon] Ramo was Whinnery's boss at General Electric in Schenectady in the 1940s.

That's his connection. Whinnery went to Berkeley; Ramo went to Hughes. And then [Ramo] cofounded Thompson Ramo-Wooldridge, all part of that early California aerospace Mafia. And then there was the Bell Labs connection—John Pierce. Do you know John Pierce? He was here [prof. of engineering at Caltech, 1971-1980]. So our research group at Berkeley around John Whinnery was really plugged into the big centers of research in the US. And professors from those places came and spent sabbaticals or visited and lectured. So we were, in a way, introduced to some of those people and ideas even in graduate school. I met John Pierce, and some of the people working with him, while I was in college.

So I did my thesis initially on topics that were John Whinnery's cup of tea, and then for my PhD I decided to do something different. I went to a meeting in Boulder, Colorado, to report on some work I did for my master's thesis, and I heard two scientists from Bell Labs report on a new invention—the maser. The maser was a precursor of the laser; it's like a laser, but the "M" stands for "microwave." The "L" in "laser" stands for light.

COHEN: Did [Charles H.] Townes have anything to do with this?

YARIV: Yes, Townes invented the maser as well. And only later he said, "Hey, we can make a maser that operates not at microwave frequencies but at light frequencies." So that's the laser. But the maser was there first, by about maybe five or six years. And I went to the meeting at which two scientists from Bell reported on the first maser.

COHEN: That's the first you'd heard of it?

YARIV: Yes, and it sounded interesting, so I decided in 1954 or 1955 to do my PhD in that field.

COHEN: Was there a literature? No, there wouldn't have been any literature.

YARIV: There was no literature. The field of physics that you probably needed to understand in order to move into that was paramagnetic resonance. And it happened that one of those two scientists was George Feher; he is now an emeritus professor at UC San Diego.

COHEN: Where was he from?

YARIV: Hungary, via Israel. He wrote an article recently describing his life; it's a fascinating document. But anyhow, George had graduated in physics from Berkeley four years ahead of me. He came from Israel, although he was born in Hungary. George was probably one of the best physicists I ever met. He was a truly natural physicist, especially experimentally.

So John Whinnery said, "OK, we'll help you." I needed some money to buy new equipment. At Berkeley at that time, that would have been a completely new direction for electrical engineering to move into.

COHEN: But Whinnery saw that this was a good idea?

YARIV: He supported me. The first thing I did was go to Bell, and I spent a week with George Feher. Before that, I read everything I could. At Bell Labs I was a guest for a week, essentially learning the system. Then I came [back] to Berkeley and built an experimental system to make masers, or demonstrate the maser principle, which was my PhD thesis. Also at the same time, because I had had the minimal mandatory physics courses that the electrical engineers needed to take—that's one year of physics in the sophomore year—

COHEN: So it's not nearly as demanding as Caltech in physics?

YARIV: That's right, at that time, but maybe the curriculum has changed. But then [electrical engineering] was separate, and they had their own curriculum. So I went back to the physics department, and for one year I essentially only took courses.

COHEN: You mean you stayed at Berkeley for another year?

YARIV: No, no. This was when I decided to switch from radio engineering to solid-state physics and masers for my PhD thesis.

COHEN: Oh, you needed more physics.

YARIV: I needed more physics. Or I needed physics, period [laughter], not more physics.

COHEN: I think there were some famous physicists at Berkeley.

YARIV: Oh, yes. My teachers were Emilio Segrè, [Luis] Alvarez, Charles Kittel. I mean, they were really a distinguished bunch. And there were other great names. William Nierenberg, who was at UCSD. I took the courses, and I did all right in the courses. I found physics was no more difficult than engineering. [Laughter] They wanted to convert me to go into physics, but I was loyal. [Laughter] I thought, "As long as I do what I want to do, what is the point?" Also John Whinnery and the electrical engineering department had helped me and the department had become a home away from home.

So it was fun. I did my PhD—I did an experiment. I built a micromaser in the engineering department, and I got out in '59. I went directly to Bell Labs. The lab was already connected to Berkeley, and I was essentially recruited before I graduated.

COHEN: You must have been quite devoted to leave the beach. [Laughter]

YARIV: Well, in Northern California in a way I already was divorced from the beach. You know, the water there is cold. [Laughter] I think I dipped in the San Francisco Bay once, and the memory was enough to keep me out of the water for four years. But every summer I would take my jalopy and— Oh, I was married in 1954, between undergraduate school and graduate school.

COHEN: This was someone you met at Berkeley?

YARIV: Yes. So we took the jalopy and drove down to San Diego to bodysurf every year. [Laughter]

COHEN: In the summertime?

YARIV: Yes. We'd take a couple of weeks. So that's how we discovered San Diego.

COHEN: Oh, that's how you know San Diego and Mission Beach.

YARIV: Mission Beach. And La Jolla has a great beach. And not many Californians even today know about it. Have you heard of Windandsea?

COHEN: Oh, sure. We lived in La Jolla for two years.

YARIV: Oh, of course you know Windandsea. Well, we discovered Windandsea and I have been going back every year since then.

COHEN: So anyway, you went to New Jersey.

YARIV: I went to New Jersey. And I joined a group working on...trying to make the world's first laser.

COHEN: These were the people that you had heard at this meeting [in Boulder]?

YARIV: No. They were at Bell [but] they were doing other things. I think for them the maser was like a side excursion. It had a very limited kind of application. JPL [the Jet Propulsion Laboratory] is probably one of the few places in the world that found a good application for the maser, and that's in their Deep Space Network.

COHEN: I know about that.

YARIV: Oh, yes! Your husband [Marshall Cohen, professor of astronomy emeritus], of course, is one of the users of that technology—amplifying very, very weak signals coming from outer space. But it didn't have many other applications, so it wasn't ever something big at Bell. The group of people I'm talking about now, in 1959, was a new generation of scientists, some of them new recruits like myself, joining together in three independent groups in different departments—in a way, competing against each other.

COHEN: Was Bell the only place you considered at that time?

YARIV: I interviewed at a couple of other places, but I don't think I considered them very seriously.

COHEN: And you didn't think of an academic career at that time?

YARIV: No. I interviewed at IBM, RCA Labs, Stanford Research Institute, and Bell. Bell, of course, was the mecca at the time for science. They were a monopoly, a telephone monopoly, which meant that they could spend their [money] on research without a limit, since doing research was the same as buying paint for telephone poles, or digging a cable trench. [Laughter] It was part of doing business. And because they were a monopoly, they were allowed expenses plus eight-percent profit. That was the recipe by which they were regulated. The more research they did, the more profit they made—eight percent on top of it.

COHEN: So they hired good people.

YARIV: And allowed them to do whatever they wanted, within reason, and gave them all the equipment, and that was that.

COHEN: But with very good results.

YARIV: Some of them, like the transistor and laser.

COHEN: Right.

YARIV: Townes and [Arthur L.] Schawlow had written—two years earlier, 1958—a famous paper on the feasibility of making an optical maser ["Infrared and Optical Masers," *Phys. Rev.*, 112, Dec. 15, 1958, pp. 1940-49]. They called it the optical maser at that time, not the laser. So there were groups all over the world—three at Bell—trying to make the first laser. And we were all convinced that it was only a question of which of our three groups would make the world's first laser.

COHEN: I see. So the competition was right there.

YARIV: We kind of dismissed the rest of the world, which is something very easy to do when you're at Bell. It was in their culture, and I was guilty of it as well.

COHEN: You thought that if they weren't doing it at Bell, nobody was doing it?

YARIV: Or if others were doing it, they weren't as likely to do as good a job as we could.

COHEN: This sounds like the beginning of a story. So then what happened? Who were you working with?

YARIV: Well, there was a group of maybe four or five of us. Each one of the groups at Bell took a different approach, chose different materials.

COHEN: And did you talk to each other?

YARIV: We talked to each other, yes, because we didn't think that we were competitors. We were competing for the same aim but by different routes. And then I happened to be on my annual vacation in San Diego. By that time, we had our first daughter. [Tape ends]

Begin Tape 1, Side 2

YARIV: And I got a phone call from my department head, Jim [James P.] Gordon, at Bell. And he said, "Amnon, there is a scientist working at Hughes Research Labs in Malibu by the name of Ted [Theodore H.] Maiman who claims to have made a laser." Remember, we still called them optical masers, but I'll call it a laser. And he said, "Would you mind taking a day off at our expense and driving up to Malibu and seeing what he has, and then call me back?" So I did drive up, and I found Maiman very nervous.

COHEN: He was nervous, or you were nervous?

YARIV: He was nervous. Imagine yourself believing that you made the world's first laser. You know, when you make it there's no sign: you don't hear the whisper of God saying, "You made it." A laser is a source of light, so how do you know it's a laser and not just [something] like a flash bulb or a burst of light? So he was very insecure. You don't want to go out and make such a statement and then have to retract it.

COHEN: So how did they hear about it at Bell?

YARIV: Because he had submitted a paper. But he was still nervous. He was ninety-percent sure, but not a hundred percent. He probably very much needed people to reassure him. So for that reason he welcomed me. He had never met me before, I came from a competitor, but he welcomed me into the lab and showed me the laser and why he thought it was indeed a laser, and I was soon convinced that what he had was special. First of all, there was a big blob of light on the wall, and all of a sudden it collapsed into a bright spot.

COHEN: I've seen demonstrations like that.

YARIV: And the only thing that would have caused that is if the light had become orderly—we call it "coherent." From chaotic light, it became organized so it could be focused as a spot. So I called my friends at Bell to tell them that we all had been scooped. There was, however, an interesting lesson in Maiman's winning the race.

COHEN: Now, which approach of your three groups was he using?

YARIV: None. You see, we all were taking what we would call approaches that would lead to a continuously operating laser—a laser that emits light all the time, like a lamp. And what Ted Maiman did was pump it with a burst of energy so that the laser emitted one burst of light and that was all. He used a photographic flash lamp, as a matter of fact, wrapped around a ruby rod, which was the laser. You can dump a lot of energy at once in a pulse into a laser. It's easier than trying to maintain the same high level over a long time, which we were trying to do. It was smarter. Also because maybe he was working alone against the orders of his superiors, who were not allowing him to work on that. That was not his assigned problem at Hughes, so he did it after hours, at night. He didn't have the support, so he really had to resort to ingenuity. It never occurred to us. In fact, when the word got out that Ted Maiman made the laser, some people were kind of pooh-poohing it, saying, “Oh, but it only works in bursts. It doesn’t work continuously.” Well, that didn’t really matter. It’s true that today most of the important lasers are continuous, but to demonstrate the principle it was good enough. Even today, for drilling holes or for military weapons and so on, we use lasers in that burst mode.

COHEN: So you admired what he did?

YARIV: Oh, I admired it, yes. I don’t think I felt particularly discouraged or saddened. First of all, there were three groups at Bell, so I knew that my chance, at best, was only one in three. [Laughter] So I went back to Bell, and indeed our group made the world’s third laser, not the second. One of the other two groups made the second; we made the third. And after a while, we discovered lots of different laser materials.

COHEN: You were at Bell Labs for how many years?

YARIV: Four years.

COHEN: And you liked it?

YARIV: Well, in retrospect.... I forgot about this, but my first wife tells me that I used to come home, have dinner, and go back until two o’clock in the morning.

COHEN: Yes, that’s what young scientists do.

YARIV: I’ve erased it from my memory. [Laughter] All of the young people who were working around us have become pioneers. It was an exceedingly good group of young people. And we really, in some ways, laid some of the foundations for the field. My boss then—the one who had called me in San Diego, Jim Gordon—and I wrote the first review article on the laser [A. Yariv and J. P. Gordon, “The Laser,” *Proc. IEEE*, 51, pp. 4-29, January 1963], which became one of the first textbooks that [laid out] the principles of lasers.

COHEN: So that was really seminal work you were doing.

YARIV: And every question we asked at that time became a basic question. A lot of publications resulted. Whatever we did, we could publish and be the first.

COHEN: Then why did you leave Bell? It sounds like it was a very productive and comfortable place, and many people have made their lives there.

YARIV: Yes.

COHEN: What made you restless?

YARIV: Well, it was not a very well-thought-out move. I looked around Bell and decided that I didn't want to grow old at Bell. I discovered some great scientists there—as a matter of fact, some of my idols. In one specific case it was a scientist whose work I had studied as a graduate student. He was a mathematician, not a scientist, who wrote a classic paper on noise.

COHEN: What was his name?

YARIV: His name was [Stephen O.] Rice. And he wrote a classic paper on shot noise. ["Mathematical Analysis of Random Noise," *Bell System Technical Journal*, 23: 282-332 and 24: 46-156 (1944)] Marshall [Cohen] would know what shot noise is: it's the bugaboo of all engineers and scientists who try to make something work. There's always a hiss in the background. Anyhow, he had written a classic paper. I always worked on noise, even today—noise in different contexts. I did some work on noise and somebody said, "Why don't you go and see Rice?" I said, "Rice is still here?" Yes, he was there. He was in the little cubicle in the corner. He was so lonely he was glad to see me. I saw other great scientists there. I figured that I didn't want to be there twenty-five years from then.

COHEN: I see. You felt that they got lost in a corner and were there until somebody dusted them off once in a while.

YARIV: Yes. And maybe I wasn't completely a hundred percent a scientist. I mean, I always liked to do other things. Bell was too specialized, or too isolated from the rest of the world.

Also, the corner of New Jersey where it was wasn't the most cosmopolitan [place]. And also, having been born in the sunny Mediterranean and having spent eight years in Berkeley, I finally needed to get back to the sun and the sea.

COHEN: You never thought about going back to Israel?

YARIV: I thought about it, but in Israel at that time—the late fifties and early sixties—there really was no research to speak of, not in the areas that I was interested in. So I had the chance to work in the world's greatest research lab in my field of solid-state physics and communication or go to Israel. I decided not to go back to Israel.

COHEN: So did offers come?

YARIV: Yes, I had a few offers. There was one from Caltech, as a matter of fact. It was not a formal offer, but informal. You know, a fellow professor, Roy Gould [Ramo Professor of Engineering, emeritus], whom I knew because Roy's specialty was what I did during my first two years in graduate school—this radio-engineering-plasma type of work. My professor John Whinnery, Berkeley, Hughes Aircraft—that was Roy's world. He was one of the great names in that field. So I had met him at conferences. And he told me that if I ever wanted to go to a university, I should consider Caltech. But I left Bell and went to work for a medium-size company in the Bay Area, actually. I didn't come to Caltech directly.

COHEN: What was the name of this company?

YARIV: Watkins-Johnson. They sold me a bill of goods. They said that they wanted to build a laser department, et cetera.

COHEN: And you would be in charge of that?

YARIV: Yes. And after all, I had studied as an engineer, and I thought maybe it would be an interesting life. So we moved to Palo Alto, where our second daughter was born. That was in 1964. I started working there, but it didn't take long for me to decide that I didn't like that kind of work. They did the work on government contracts, and it didn't really matter what you did as long as you got the money to do it. Once you got to work, it was clear that the people above didn't care what you did; there was just the pressure to bring in more contracts. So I decided to leave, and I left. I remembered Roy Gould's invitation of a few years before. I called Roy. In the meantime, I had an offer from Berkeley and UC San Diego. I interviewed in all those places, and I decided to come to Caltech.

COHEN: A good choice. OK.

YARIV: It was right for me. So that was September of 1964.

COHEN: When you came, what position did you have?

YARIV: I came as an associate professor of electrical engineering.

COHEN: Now, did you tell me when we were talking at lunch that you also had an offer from Cornell?

YARIV: Yes, that's right.

COHEN: As a full professor?

YARIV: That's right. I went to Cornell and had an offer, but I came to Caltech as an associate professor.

COHEN: OK. It's closer to the beach. [Laughter] So did you set up your own lab right away?

YARIV: Yes, right away.

COHEN: When you came, in '64, was electrical engineering a part of the engineering division or was it still a part of physics?

YARIV: No, it had already split.

COHEN: It was part of the engineering division.

YARIV: Yes, but it was its own department. Roy Gould was then, I think, still a professor of physics and electrical engineering.

COHEN: OK. And you were just a professor of electrical engineering.

YARIV: Yes.

COHEN: And your idea was to set up a laser laboratory?

YARIV: Yes. There was actually a professor at Caltech already doing laser research.

COHEN: Who was that?

YARIV: Nick George. He was doing some laser research. And I started to build up a lab. During my last year or two at Bell, I had started working in a specific direction in lasers—semiconductor lasers. You know, there are thousands of different lasers today utilizing different materials and different processes for exciting them. Some are huge tabletop ones. Some you need a magnifying glass to see; those are the semiconductor lasers, and they are really like transistors in their internal workings. The semiconductor's currents are small. They were not invented at Bell; they were invented at IBM Research Lab. But a bunch of us at Bell started working with them, I among them, and that became my major research direction. So when I came to Caltech, that's what I started working on.

COHEN: Now, this is really interesting to me. When you work on a specific thing, like a laser, is the idea to use it for something?

YARIV: No.

COHEN: It's just to create?

YARIV: At that time, [the idea] was not to use it but just to create it and study its basic properties. You see, optics, the study of light, is a major field by itself. That's what Jeff Kimble [Valentine Professor and professor of physics] is doing, for instance, or [Hideo] Mabuchi [assistant professor of physics]. They're working with light—light as a medium. You've heard of the field of nonlinear optics, which is a major [field].

So we were working on making new lasers, and with them studying properties of materials and applications that were made possible only by the availability of laser light.

COHEN: I do remember when it first started. People went to see laser shows.

YARIV: Yes, yes. I was interested in the basic properties of lasers. We also worked here on mode-locked lasers, which emit ultrashort pulses of light, as well as in nonlinear optics. [Tape is turned off]

AMNON YARIV
SESSION 2
November 24, 1999

Begin Tape 2, Side 1

COHEN: I'm just going to go back a little bit, to ask you about Bell.

YARIV: Oh, I guess I was talking about an attitude at Bell that probably isn't there much anymore, because Bell is not as good as it used to be. It's smaller and they are very much product-oriented now, so they don't do the kind of research that really attracts the research-oriented graduate students.

COHEN: Now, is this Lucent Laboratories that you're talking about?

YARIV: Bell is now Lucent. The name "Bell" goes with the Lucent Laboratory. AT&T, which broke away from Lucent, has its own laboratory, and I think they call it AT&T Laboratories.

But in the olden days, Bell was so large and so good that there was a kind of built-in assumption that if something wasn't done there or thought of there, it wasn't worth mentioning. [Laughter] This wasn't a policy promulgated by the powers at Bell, but the result was that there was a tendency to treat with disrespect work done elsewhere. And I was as guilty of that as anybody else at Bell. But when I left Bell, I was on the receiving side of that philosophy all of a sudden. [Laughter] And a particular example is an invention we made at Caltech, somewhere maybe in the early eighties. At that time it didn't seem very important, so it was kind of relegated. We wrote two or three papers. And then, about eight years later, a paper was published by Bell Lab scientists which essentially reinvented—

COHEN: Now, what was this?

YARIV: It was a new type of detector for infrared radiation, based on transitions between quantum wells, which were kind of a new invention, which made it possible to tailor the detector to the wavelength you wanted to detect specifically. It was a new idea, and Bell reinvented it.

Probably, in all honesty, they were maybe not aware of our work when they did this, but we pointed it out to them. No—actually in the first paper our work was acknowledged; they gave us credit. But then in the hundred papers they wrote after that, they never mentioned our work. So the field became popular and attracted a lot of people, and most of those people who were attracted to it and read the literature probably had no idea—

COHEN: That the idea was from here?

YARIV: Yes.

COHEN: OK, so you left the Bay Area, because you realized that it was not so attractive to you.

YARIV: Yes.

COHEN: And you came to Caltech. You had already heard from Roy Gould that there would be a place for you if you ever wanted to come.

YARIV: So I called Roy, and it turned out that Roy was in Australia. But there was a professor [of electrical engineering] here, [Robert V.] Langmuir. Langmuir had never heard of me. Roy was on sabbatical, or maybe he was at a conference in Australia. So he called Roy long-distance and they invited me to come to Caltech. And in short order—maybe the whole thing took a month or so—they made me an offer and I came down here, in September of ’64.

COHEN: Right. And the engineering division chief then would have been—

YARIV: Frederick Lindvall.

COHEN: In those days decisions were made quickly.

YARIV: Yes. It was probably the tail-end of the old Caltech.

COHEN: So this was your first position in academia. What did you find here when you came? How did it seem to you?

YARIV: Well, things happened quickly regarding my decision to come to Caltech, so I really didn't know what to expect. And the beginning is usually very scary, because you have no plan. I didn't know the territory, so it was a new game.

COHEN: Had you given a talk here?

YARIV: Oh, yes. I was invited and I gave a talk, and then the offer was made after the talk.

COHEN: But that was really your first experience with Caltech—coming down to give this talk?

YARIV: Yes. I had never been on the Caltech campus prior to that. I'd heard of Caltech, of course. As I mentioned, I knew of Roy Gould, I knew of some of the graduate students here, but I'd never been here.

So I felt more or less that I had burned my bridges. I could have gone back to Bell if I had wanted to, but having left it [laughter] my ego probably wouldn't have let me do that. And there were other reasons. Anyhow, I had a new job and I was doing what I needed to do. Caltech gave me a fair amount of money to set up a lab and equip it.

COHEN: Was this a new field for Caltech? Was anybody doing this kind of laser research?

YARIV: There was Nicholas George. He was here before me [Caltech PhD 1959; then as assoc. prof. of electrical engineering—ed.]. He was [originally a graduate student] who did some more conventional electrical engineering, and in the early days of lasers, before I came here, he actually had a laboratory and students doing experiments with lasers. But he was the electrical engineer type, whereas I came from a background in solid-state physics, so I really got involved more in the physics of lasers, making the lasers, especially semiconductor lasers and solid-state lasers. Nick George worked with gas lasers, like helium-neon, which is a different variety. When I came to Caltech, I actually started teaching a course in solid-state physics.

COHEN: Were you also part of the physics department?

YARIV: No, I was not, but when I came here physics was almost entirely elementary particles and astrophysics. There was literally zero solid-state physics.

COHEN: Murray Gell-Mann had a name for it, which is part of the reason. Do you know it?

YARIV: I've heard it, but I think I've forgotten it.

COHEN: Squalid state.

YARIV: Squalid-state physics [laughter], OK. It was unthinkable to me that a university didn't have solid-state physics, so I started teaching a course in solid-state physics, but it was an electrical engineering course.

COHEN: Did [Caltech] want you to do this, or did you say you would do this if you came?

YARIV: It was my initiative. I felt that to get students to do my kind of research, they needed solid-state physics. And I think from the beginning there was a good response; a lot of students showed up—physics students as well.

COHEN: Well, that was the only way they could learn it, because they couldn't learn it in the traditional physics core.

YARIV: That's right. And then I also started teaching a course on laser physics, which is essentially the interaction of electromagnetic fields and atoms, and the electromagnetic theory of lasers. We called it Quantum Electronics. I guess this was possibly the first academic course in quantum electronics.

COHEN: Here, or anywhere?

YARIV: Anywhere. There was no text. So we may have been the first—or among the first—to start teaching laser physics. Today every research university must have three or four types of courses dealing with aspects of coherent light generation, how to use it, phenomena, nonlinear optics—but not then. And after a few years of doing it, I wrote a book called *Quantum Electronics* [Wiley & Sons], which was the first text in the field.

COHEN: Now, where did the name come from?

YARIV: Quantum electronics was the name given to the field and it stuck. I'm not sure whose it was, but the name wasn't my contribution. It's not a bad name, because lasers deal with electrons—it's electrons that generate the light—although it's not electronics in the sense of electronic circuits or transistors. And "quantum" is there because we use transitions between quantum states.

The field is really divided into what you might call quantum electronics—it's really the physics of lasers and the interaction of lasers with atoms and molecules—and what's called optical electronics, or photonics, which is more the application of lasers, like optical communication.

COHEN: OK. So you were teaching the quantum electronic part of it?

YARIV: Yes, but after a while I started teaching a second course.

COHEN: When did you write the book? While you were teaching?

YARIV: Well, you know how a book is written. You first teach it, and you have class notes, and after you've done the course for two or three years, you think that you have written the book, or most of it. So when you get the annual visits from the book publishers and they ask you, you say, "OK, I have a book almost finished." So you commit yourself; you sign the contract. And then you start to actually write the book, and you find out that you've done maybe only one-third of the work, but by then it's too late. [Laughter]

COHEN: Did you enjoy writing?

YARIV: Actually, I think I enjoyed it. I was at times obsessive, because when you start writing, you just can't stop. Part of it is because you want to get rid of it, because it interferes with the rest of your life.

COHEN: So you didn't take any leave or time off to do this?

YARIV: No. I wrote it in the evenings, on weekends, on vacations.

COHEN: You must have been good company. [Laughter]

YARIV: [Laughter] I lost a wife in the process. So I wrote the book and got a few graduate students—first one, then two—and started doing experiments. What we concentrated on were lasers based on semiconductors. Those lasers are essentially somewhat like transistors in their structure, although they are not based on silicon. Silicon, for reasons I don't have time to go into, doesn't lase; it cannot make lasers, due to some of its properties. But other crystals [do]—semiconductor crystals, like gallium arsenide, and so on. So we started working with semiconductor lasers. They are also very small, and they are fed—pumped—directly with current. You connect two wires to the two leads from a battery and *voilà*! The light, if you've done things correctly.

It was tabletop physics, and that's part of why it attracted me. Also, [it attracted] students, because a student can do the whole thing himself, from beginning to end. I think I had graduate students after a few months. It turns out that the field became known. You know, now we're talking about the middle to late sixties, and by then lasers had been around for seven or eight years and there was an increasing curiosity, and very good students wanted to move into it. So they came from the physics department and electrical engineering. There was no applied physics yet at Caltech. And as I said, we concentrated on semiconductor lasers and also on an area known as nonlinear optics, which is a branch of laser physics but a specialized branch—a branch, incidentally, in which Nicolaas Bloembergen got the Nobel Prize [1981]. That was also an area of interest, and that relates to some work we did later on. So I kept those two efforts in parallel.

COHEN: It was really pioneering work.

YARIV: Well, there were not too many efforts anywhere at the beginning, so whatever you did was, yes.

COHEN: Now, did you have to get grants for this? Or didn't you need so much money? How did that work?

YARIV: Yes, I did have grants. It turns out that in the early days there was a great deal of interest among the sponsoring agencies—the Office of Naval Research, the Air Force Office of Scientific Research—in lasers. They believed, rightly or wrongly, that [lasers] had military applications, so they started supporting basic work. You know, ONR supports basic work, like astronomy.

COHEN: They were very good in those days.

YARIV: Yes. So we had adequate support. You could do what you wanted to do. There was not too much competition, because only a handful of schools were [doing this]. That changed greatly, partly because of our own work. Our own students, who then flooded the market and competed for the funds. [Laughter]

COHEN: And you still were in electrical engineering, you were not connected with physics?

YARIV: No. There was a time when I was offered—not formally—the possibility of joining the physics department, but I'm not a good committee faculty member. I've very seldom worked on any committees. And I felt guilty already about not taking part in EE [electrical engineering] committee activities. I didn't see the point of feeling twice as guilty. [Laughter] And because of the flexibility of Caltech.... You would think that to get hold of physics graduates, I would have had to join the physics department, but—

COHEN: They came anyway.

YARIV: Yes. There were no barriers; to this day I have physics students working for me. So that was not a problem. So I did not, although later on I was probably the instigator of an applied physics [program] at Caltech. Again, we were still at the stage when the physics department was not pursuing any research in solid-state physics or in optics, which is not true today. And it was clear that there were students who came to work for us, but because they came from a physics background they wanted a physics label, probably more for emotional reasons than anything else. Also, we felt that to reach into [the group of] talented students, let's say from physics in other schools, an applied physics label would be beneficial, so we started an applied physics program [1970]. I started it; some other faculty members joined. And to this day I'm a member of both the applied physics and electrical engineering [departments], although physically I'm in the Watson building [Thomas J. Watson, Sr., Laboratories of Applied Physics]. Applied physics is part of the engineering division, because that's where it started, but there are some joint appointments now: David Goodstein [professor of physics and applied physics] is one, and a few other faculty members.

COHEN: But your appointment has always just been in engineering?

YARIV: That's right.

COHEN: So the applied physics was then started, and that must have been quite successful. Who else was involved in this?

YARIV: At first Tom [Thomas C.] McGill [Jones Professor of Applied Physics], Roy Gould, Marc-Aurele Nicolet [professor of electrical engineering and applied physics, emeritus]. Later Bill [William B.] Bridges [Braun Professor of Engineering], who's also EE. Ahmed Zewail [Pauling Professor of Chemical Physics and professor of physics] was a member, and is probably still a member. [William A.] Goddard [Ferkel Professor of Chemistry and Applied Physics], in chemistry, is a member. Kerry Vahala [professor of applied physics], Harry Atwater [assoc. prof. of applied physics], Axel Scherer [professor of electrical engineering, applied physics, and physics]—

COHEN: Applied physics actually stands by itself in the engineering division?

YARIV: That's right. We have our own executive officer. Of the few places who [do applied physics], I think we are rated number one nationally, so we're small but very effective.

COHEN: Is nuclear energy part of applied physics also?

YARIV: No. Applied physics also included Roy Gould and Paul Bellan [professor of applied physics]—the plasma activity.

COHEN: Right.

YARIV: And Noel Corngold is now a professor of applied physics. I think he used to be in nuclear engineering, but he stopped doing that maybe ten or fifteen years ago and essentially joined Paul Bellan and Roy Gould, and that activity moved into our building.

COHEN: I also wanted to ask you about your relationship with Israel during this whole period. You've always had some relationship, and I don't know quite what that was or whether you want to talk about it.

YARIV: Yes, we can talk about it.

COHEN: Aside from going back to see your family, when did you start having a professional [relationship with Israel]?

YARIV: Oh, I think maybe as long as twenty or twenty-five years ago. I went to Israel and gave talks a few times before that, mostly at international conferences. But then I was asked by Tel Aviv University to become a member of the Sackler Institute [of Advanced Studies]. The Sackler Institute was endowed by [Mortimer and Raymond] Sackler—two brothers, I think. Sackler also gave Caltech money at some point. There were Sackler fellowships at Caltech, and I think the fellowships had an Israeli connection; I think they had to be awarded to Israelis or Americans who wanted to go to Israel. And they endowed a program at Tel Aviv University which brings guests to spend anywhere from a month to a year at the university. Yuval Ne'eman ran it. They have a few permanent members, and I am one of those. It means that I've gone there every year for the last twenty or twenty-five years. They give me an office, and I roam around the campus and give a couple of lectures to the students. Through the years, I've gotten to know the professors and so on, so I feel quite at home when I go there. I work with students, and some of them have later come as postdocs to Caltech. Some have gone back and become professors there. So it's a very nice relationship.

COHEN: That's an academic relationship. Why did I think that you had some army or intelligence relationship?

YARIV: If I had them, I couldn't acknowledge them. [Laughter]

COHEN: Oh [laughter], wrong question.

YARIV: Yes, absolutely. [Laughter] But I did not. If I did, I probably would have been in jail by now.

COHEN: Oh, OK.

YARIV: You can't have such things—especially since I also, working in the US, became a consultant to DARPA [Defense Advanced Research Projects Agency], and so on, so I have a military clearance.

COHEN: OK. And by now you're of course a citizen.

YARIV: I'm an American citizen. So that would have been a—

COHEN: Conflict of interest, as they say. [Laughter]

YARIV: Yes. [Laughter] So, no, [my connection with Israel] is purely academic.

COHEN: And that is just an extension of what you are doing here?

YARIV: Yes. It's the chance to attract another group of students. It is really, basically, an excuse to live a month in Israel every year. [Laughter] That's the main reason for my doing it. It isn't scientific, it's the social and cultural roots—polishing my roots.

COHEN: Of course. And you still have family?

YARIV: A large family. I even keep an apartment. When my parents died, my brother and I decided to keep their apartment in Tel Aviv. We go back, I roll up my sleeves and wear shorts—

COHEN: And go to the beach.

YARIV: And raise my speech about two decibels. [Laughter] It's a lot of fun.

COHEN: So then—coming back to Caltech—you did not get involved here in committees and—

YARIV: Not much. Over the years, I probably had one of the larger research groups at Caltech. At some point I had something like eighteen or nineteen graduates and three or four engineers and a number of postdocs. So [committee work] was simply impossible. You know, I did some work on ad-hoc committees—nomination committees, promotion committees, search committees—but it's true that I was not part of the committee world at Caltech. There simply was not enough time in twenty-four hours. We worked in two or three research areas. So there wasn't much time.

COHEN: Did you go on any sabbatic leaves?

YARIV: No, I didn't.

COHEN: It's not part of the program here, but people still do it.

YARIV: Yes, but I didn't—mostly because I started running a large experimental program, including labs. And that's, in a way, like running a small company. There are decisions about salaries and equipment, and it's more difficult to go away. I mean, it's nice to be a theoretician: have pencil, will travel.

COHEN: Right. [Laughter]

YARIV: Had I gone on a sabbatical, I'm sure I would have spent a good deal of every day on the phone—before e-mail—taking care of the problems. And there were other, psychological reasons. To me the United States was a second culture. I wasn't born in the culture. I think probably a lot of people need to live in another culture and find it interesting. Well, it's interesting to me, too, but I've done it once. So I find it easier to take trips for two or three weeks than to go for half a year or so.

COHEN: OK. So you said you branched out into three different directions.

YARIV: Mostly two directions: quantum electronics, or lasers, would be one direction, and another is nonlinear optics. Those were separate laboratories. A student would usually not work in both areas, just one or the other. And at that time—maybe 1967 or so—I wrote a paper in which I suggested the possibility of making.... Remember, we made lasers in semiconductors. Semiconductors are also materials from which we make transistors. So I wrote a paper proposing the possibility, the idea, of making electronics to control the lasers and waveguides to control the light—to take it from one place to another—all on a single crystal. Instead of connecting them and having a tabletop experiment where you have a laser emitting light into air and a lens collecting it, putting it into a box, where you turn it on and off to control it—to do it all on one crystal. In the paper, I showed that there were crystals in which all of those various functions—the generation of light, the guiding of light, turning it on and off, detecting it, converting it back into electricity—the same crystal can do all of that. So there was no reason why you couldn't have what I called integrated optoelectronic circuits. Later they became known more as electrooptic integrated circuits. I think that's the name today; it got reversed.

COHEN: Now, this was an idea, or you had actually tried this?

YARIV: This was an idea at that time, pure idea. I wrote a paper and gave a number of talks, and one of them was in Japan. At the end of my talk, somebody came up to me and introduced himself. He was from DARPA.

COHEN: Not a Japanese?

YARIV: No. And he asked me if I would like support for the work [laughter], if we were doing it experimentally. I said, "No, it's not yet [at that point], but we'd like to do it experimentally." So I said, "Of course." [Laughter] So to make the story short, that started a research-support relationship with DARPA that is still going on, over thirty years.

COHEN: They were generous, I gather.

YARIV: Oh, yes. I had enough money to do the work. You know, we were not drowning in money, but it was good support. And also we had continuing support from the ONR and the AFOSR [Air Force Office of Scientific Research]. So along with the three agencies, we started working on illustrating that idea.

COHEN: Did you make the crystals yourself?

YARIV: I've brought you an invited article I wrote some years ago, in '84. I was asked to describe the beginning of that field, and I did, so I'll give it to you. It has much of the background, dates, personal stories, and the first graduate student who did it. But when you read it, you'll find out that the first crystals that were used were not grown here. We begged for them. But because the field did not exist, those crystals were not made for our purpose; they were there for other reasons. So we had to go around and see if we could find [them], and eventually we found a crystal at United Aircraft Research Laboratories, in Hartford, Connecticut, grown for completely different reasons. The father of the graduate student [David Hall] whose PhD project it was worked in that lab, so the graduate student knew somebody there. He brought a crystal back and we saw the first effect: we were able to guide light in the semiconductor crystal and turn it on and off. [D. Hall, A. Yariv, and E. Garmire, "Observation of Propagation Cutoff and Its Control in Thin Optical Waveguides," *Appl. Phys. Lett.*, 17:3, pp. 127-29 (1970)]. That was a key, pivotal experiment.

COHEN: Can you say what made you have this idea?

YARIV: I really don't know—just working in it. I don't recall the "eureka" moment. [Laughter] It may have been gradual. You see, this experiment already—the experiment I've described here—preceded the idea. We had already done two things on a crystal: we had guided light and we had controlled it, or made a gate.

COHEN: So your idea was to combine these two functions in one crystal?

YARIV: Yes, but when we combined the two functions, it wasn't clear to me at the time. I didn't see the greater vision of combining a lot of other things, so that you could make complete optical circuits.

COHEN: All in a crystal?

YARIV: Yes, both transmitters and receivers. But in a way we had taken a small step, and at some point we said, "Hey, since we've combined two functions, why not three or four? What can one do?" And then through a systematic approach, you'd get a crystal with physical properties. What properties can be used to generate light? What properties can be used to modulate it, to transport it? That came gradually, but there was a moment when we realized we could do a lot more than we had done, so we proposed it and we got the support for it. And then we got a very talented postdoc who came to us from Israel. His name was Shlomo Margalit. He was one of those gifted people who just lives and breathes science. He also breathed cigarette smoke, unfortunately. [Laughter] He was extremely practical with his hands. So with his help, and the help of graduate students, we succeeded in making the world's first optoelectronic integrated circuits.

COHEN: What material were your crystals made of?

YARIV: The material we used initially was gallium arsenide. And a related crystal, gallium aluminum arsenide. And here you'll see a picture. This is figure no. 7 in this article. What you have here is a laser, and the laser is fed by current. You put current into a laser and out comes light. That's the property of semiconductor lasers. And the current here is supplied by a transistor. So we're making a transistor next to a laser on the same crystal, and that was a big step.

COHEN: Give us the name of the article.

YARIV: The paper is called "The Beginning of Integrated Optoelectronic Circuits," and I'm the author. It appeared in the *IEEE Transactions on Electron Devices*, volume ed-31, no. 11, November '84. It's a kind of retrospective; it doesn't describe the original work. The original work is listed here in a number of articles. And I see that the first paper from Caltech is in 1970 [D. Hall, A. Yariv, and E. Garmire, "Optical guiding and electro-optic modulation in GaAs epitaxial layers," *Opt. Comm.*, 1:9, pp. 403-405 (Apr. 1970)]. David Hall was my first graduate student. Then there was myself and Elsa Garmire, who joined us as a postdoc. She was a student at MIT. She had just shown up here that year and joined our group as a postdoc.

COHEN: She was Townes's student, wasn't she?

YARIV: She was a student of Charles Townes, and she did some important PhD thesis work. Then she became a professor at USC [University of Southern California].

COHEN: Is she still there?

YARIV: No, she left about four or five years ago to go to Dartmouth as dean of engineering. And then she retired from that job; I think she's retired now.

So that became, and to this day has continued to be, a discipline—integrated optoelectronics. There are still sessions and conferences, and it is now no longer really an academic discipline. Now practical devices of increasing complexity are made and sold which combine different functions on the same crystals.

COHEN: That's done in companies themselves; it's not done on campuses anymore?

YARIV: It's done almost completely at companies. Once we did our first four or five experiments demonstrating the feasibility of this idea, it was clear that the next step would require teams of engineers, crystal growers, electric circuit designers to make it. And it became too big a job for a university, and not one that should necessarily be done at a university.

COHEN: What separates what should be done at a university and done in a company?

YARIV: That depends very much on which university it is. At Caltech, my criterion is that if you can write a thesis on it and justify it, then it should be done at a university—meaning original work. But the word "original" is a very subjective word. And there are different standards of how fundamental the work should be—so what one university will not do, other universities will do. So that really went down the chain, and other universities did it for years. But what we realized—fortunately very early—was that once we put the word out, we were not necessarily the best people to carry on the work. We would probably not be able to stay in front.

COHEN: Because it would take too big a group?

YARIV: Too big an effort, which we didn't have. You know, from the point of view of a researcher at a university, once you demonstrate an idea and you put it out, you've had eighty percent of the fun and the enjoyment of doing it, and possibly even most of the credit. People who come after you have to work a lot harder. [Laughter] So theoretically, if you can move to another area, if you have a choice, it's preferable.

COHEN: Once it works, it's not so interesting anymore.

YARIV: Less interesting. We stayed with it for four or five years.

COHEN: So you had quite a few students that went through and did theses on this?

YARIV: Probably four or five students got their PhDs working in this area. But remember, this was an outgrowth of, and always alongside, our work in semiconductor lasers, which we never stopped. We were working on understanding the basic properties of semiconductor lasers. The semiconductor laser, in retrospect, is the most important optical component. It's a component that powers the whole Internet generation—the source of the light. And semiconductor lasers are very rich in phenomenology. They include all the physics of transistors—the electrons and holes moving and different semiconductor types. Optical properties of electrons and holes. It also has optics in it—electromagnetic phenomena, generation of light, optical resonators, et cetera. So it's a very rich animal from the research point of view. It's also the most efficient converter of electricity to light. In a good semiconductor laser, for each electron that is injected from the outside, you get a particle of light, or a photon, out. And you lose very little energy, so we can reach conversion efficiencies of eighty or ninety percent, while tabletop lasers, the big ones, are maybe a percent or a fraction of a percent in efficiency. The physics was rich, and it was clear early, to some of us, that it was going to become a very important laser. But that didn't really happen until the optical communication field appeared on the scene.

In the early days, the early seventies, optical communication—the transmission of information over fibers with lasers—did not exist, because the fibers did not exist. At Bell Labs they actually had a big project of sending laser light beams from coast to coast in big evacuated pipes with lenses placed at fixed intervals along them to refocus the light. That project went a long way, and looking back on it, it was an unbelievably crude kludge, but that was the only thing on the horizon. The benefits of transmitting information via light were so overwhelming that people were willing to try even that. But then a newly minted English PhD by the name of Charles Kao, a Chinese immigrant, came up with a great idea that one should be able to send laser light through fibers: the fibers would guide the light the same way that a water pipe guides water. People laughed at him at first. People were using fibers to guide light—but, for instance, in a Christmas-tree pattern. You've seen it in light fountains; the light comes out from a bunch of fibers and it looks like a tree, and if the fiber is longer than six or seven feet, there's no light left—the light just completely disappears along the way. So people knew that it was not a proper medium for guiding light any reasonable distance. Charles Kao reasoned that this was because the fibers were dirty, contained impurities—a *schmutz* effect, which absorbed the light. And if you went to a great deal of trouble, in making the glass, to get rid of those impurities—like residual iron atoms—then the absorption would lessen. And he was right.

COHEN: Where was he doing his work?

YARIV: He had graduated from the Imperial College of London. He was a young Chinese student from Singapore. And I think he did his work in some English company, in a research lab. [Tape ends]

Begin Tape 2, Side 2

YARIV: Based on Kao's work, Corning, in New York, a big glass company that in those days used to make cooking appliances, started fiber research.

COHEN: They also made the parts for Palomar. [Laughter]

YARIV: Yes. They don't do any of that anymore; all they do now is optical fibers and related stuff. They sold off their cookware business. Anyhow, the scientists at Corning indeed purified glass. They are probably the best glass chemists in the world. So they made very pure glass, pulled it into fibers, and lo and behold, you could send the light a kilometer instead of two or three meters—a factor of 1,000. And there was still some useful light left. To make a long story short, that work, and improvement upon it, led to fibers with which you could actually propagate light for forty or fifty kilometers and still have useful light. What's more, now we also know how to amplify the light back to the original level, so it can keep going right across the US. Anyhow, all of a sudden we had a medium—the optical fiber, a pipe for light. So of course this Bell Labs effort to send light in evacuated pipes was discarded overnight and everybody started making fibers. But you needed a light source for the fibers: you needed a laser. And it turned out that this little laser we had been playing with here at Caltech—for reasons unrelated, because we didn't know that Charles Kao was going to invent or introduce the optical fiber—turned out to be the ideal light source, because the fiber is just a pipe. The light is generated in the laser, and semiconductor lasers, to begin with, are very, very small. Their dimensions were just right for the light to essentially butt them onto a fiber—so the light leaving the laser enters the fiber.

What's more, they were very efficient in converting electric current to light; they had the right color to go through the fiber with minimal absorption. I mean, it was one of those juxtapositions—

COHEN: A marriage made in heaven. [Laughter]

YARIV: That's right. And they had one additional property: you could turn them on and off, because what you did was feed current into them, and the current was transformed into light by the laser. If you could control the current going into them, turn it on and off, you would cause the light to go on and off, and therefore that's your bits, 1s and 0s—with 1s corresponding to light on and 0s corresponding to light off. So if you somehow could freeze the propagation of light in the fiber—take a snapshot, say—you'd see bullets of light. Each one is one bit.

COHEN: Pulses of light.

YARIV: Pulses of light propagating. Between them you'd see dark spots—those are the zeros—the 1s and 0s of digital communication. So that brings us to where we fit into the picture. A graduate student in my group, Kam Lau, was the first to demonstrate the ability to turn the light on and off at fantastically high speeds. Today he's a professor at Berkeley. He was a Caltech undergrad who joined our effort—a very, very talented student, theoretically and experimentally—and when he started working with semiconductor lasers as part of the research effort, it was considered in the field that the highest speed at which you could turn them on and off was about 2 billion times a second. Now, that's quite fast. And it was considered to be a roof—you couldn't go beyond that, for reasons that would take too long to explain. Kam Lau found out that the reasoning that led to that conclusion was flawed and that there was basically no real limit, and he immediately pushed the roof up by a factor of five. In the lab at Caltech, he was able to demonstrate modulation speeds of 10 billion times a second, which is roughly the speed of today's lasers in the real system. [K. Lau, C. Harder, and A. Yariv, "Ultimate Frequency Response of Ga As Injection Lasers," *Opt. Comm.*, 36, pp. 472-74 (1981) and "Direct Amplitude Modulation of Short-Cavity Ga As Lasers up to X-band Frequencies," *Appl. Phys. Lett.*, 43, pp. 1-3 (1983)] It took that many years for industry to demand that level of speed—to actually apply it to the real systems—because there were other obstacles, having to do with the fibers, which had to be overcome. It so happens that today's communication systems use data rates of 10 billion bits per second.

COHEN: It's hard to imagine these numbers, but OK.

YARIV: That number is big enough so that if everybody in Los Angeles were to talk on the telephone at the same time and you took all of those conversations and compacted them and interleaved them, one laser could launch them all.

COHEN: It could take care of all that communication.

YARIV: Exactly. Something else happened at about the same time. People started, because of the fibers—

COHEN: Did you tell me why you suddenly realized that your stuff would work with the glass fibers? What made it come together, what made you think of this?

YARIV: The size of the laser beam. You see, the diameter of the fiber is roughly 100 microns, about the thickness of a human hair. And it's made up of an outer layer and an inner core. The core is only 10 microns, and that's where the light is concentrated. And the semiconductor laser puts out a laser beam roughly that size.

COHEN: Ten microns?

YARIV: Yes. When I told you about the ability to transmit light in glass long distances, that's only true for a certain color, or wavelength, of light, because the absorption of light in silicon is a very strong function of the wavelength, and there is a window there—around wavelengths of 1.3 to 1.6 microns—where the absorption is very low. And you can tailor the composition of a semiconductor laser chemically so that they emit light exactly in that region. They are also very efficient. You don't have to put kilowatts of power into the laser—[you can use] milliwatts. So all these things came together to make the semiconductor laser the obvious choice as a source.

And then you also had the ability to turn it on and off, which you needed to do to put in information. Just putting light into a fiber doesn't do any good; information means interrupting, modulating. And a transistor is what does the turning on and off. We had learned to make transistors on the same crystal.

COHEN: Was anybody else doing this?

YARIV: Oh, yes. By that time, every industrial electronics research lab in the world was doing it, because this was now becoming recognized as the technology at the basis of optical communication. Of course, that was before the Internet, so optical communication had not yet taken off in a big way. But the future did look bright, in an infrared type of manner. What happened at that time was that conventional telephony, which was using copper wires, was moving to fibers. And that already was a big enough business to make it exciting—though not nearly as exciting as it is today with the Internet. [Nowadays] the telephone business, or voice conversation, is becoming the minority of the traffic. But that was the transition then—taking over long-distance telephony.

Probably two-thirds of our effort at Caltech was, basically, various aspects of semiconductor lasers. Let's see if we have a picture in here. Oh, yes—this is a picture of a semiconductor laser, magnified by–

COHEN: We're talking about the same paper?

YARIV: Yes. It's the same paper I cited earlier. You can see many layers here. Those layers are grown in the laboratory. By that time, we had been making our own lasers. We set up a lab for growing these crystals. And each layer has a different chemical composition, all of them related, let's say, to gallium arsenide, but different doping, different composition. And current is fed. You connect the top to one side of a battery, the bottom to another, and light comes out of here. But if you take an ordinary semiconductor laser, the light generated by the laser is not pure: it has many colors simultaneously. And that was detrimental for long-distance optical communication. It turns out that the light, when entering the fiber—and remember, what you are launching through the fiber is pulses, on-off, on-off, 10 billion times a second—because of basic and unavoidable properties of physics, those pulses broaden in transit. After sufficiently long distance, they begin to merge into each other and you lose the identity of the 1 and the 0; that is, you lose the information. If the laser is not pure spectrally, meaning if it doesn't put out a pure single color, that happens at shorter distance.

Anyhow, about that time, we made a laser that was like a conventional laser. But for an academic reason which I've forgotten now, it had a built-in wavy interface between two of its crystalline layers—like a corrugated washboard surface. So in the process of growing the laser, we interrupted the growth, took the crystal out, made this washboard surface holographically, and then put it back and continued growing the remaining layers. It turns out that the waviness—periodicity, as we call it—is related to the Bragg scattering effect in physics. And the net result is that that laser now emits a pure tone—only a single color, the wavelength that resonates, Bragg-wise, with the period of corrugation.

COHEN: So your washboard was sort of an interference, in some sense.

YARIV: That's right, exactly. What happens is that light is reflected from each one of those teeth, and at the right wavelength all those reflections add up—that's called constructive interference. Every laser needs reflection, or feedback, to oscillate. The feedback here is provided not from the ends, [as with] all other lasers, but internally, from the corrugation. That fixes the wavelength at a single value.

COHEN: So that was a real breakthrough.

YARIV: We made that laser before the need arose, so to speak—that is, for academic reasons. I've always had a long love affair with periodic phenomena. And there's a history, which we don't have time to go into, but part of it resulted in deciding to make a periodic laser. And the timing was right. All of a sudden, that laser solved a real problem, which wasn't the reason we made it. That laser—which is called a distributed-feedback laser, because the feedback is distributed along the length—is now the mainstay of the whole optical communication field.

COHEN: Is that right? The whole thing is based on this? Did you ever get patents on these things?

YARIV: When I came to Caltech, I wasn't patent conscious, and we did not take out a patent on that. That patent could have made a lot of money for Caltech. We were too busy. We were not thinking about patents. That happened later, when we became more savvy. But nothing we made later was as important. [Laughter]

COHEN: [Laughter] So you mean there was no clear policy on this? Nobody thought about this?

YARIV: I think there was a patent attorney at Caltech. There probably had been one for a long time. You know, nobody at Caltech hounds you. When I was at Bell Labs, the patent attorney would show up, on average, once a week, knocking at the door. He'd say, "Yariv, do you have any ideas which you could patent?" And I would scratch my head and say, "I don't think so." But occasionally you said, "Yes, I think so," because they would push you into patenting ideas. That's not done at Caltech, not even today. It's up to you to write a disclosure. Well, today I'm more patent conscious, and I do it. I did it yesterday on some idea. But we didn't do it at that time. And there was no mechanism at Caltech—you know, we were a university.

COHEN: But you have gotten credit for this idea?

YARIV: Oh, yes. At that time we were mostly credit conscious. [Laughter] Anyhow, that covers our work in semiconductor lasers. We are still working with them, but a little less.

COHEN: So you left this when the idea was formed and you then went on. What did you go on to then?

YARIV: Well, by that time—let's say 1979 or so—we found ourselves here with students who could make the world's fastest lasers, and lasers that industry, at the time, didn't know how to make. And they knew how to grow them from scratch and do everything necessary. As a matter of fact, air force laboratories and some aerospace companies, like Boeing and Hughes Aircraft, had asked us for some lasers, because they could not get them, and they could see applications for them. If you can turn a laser on and off at the rate of, say, 10 gigabits—10 billion times per second, a range of frequencies known as microwaves—you can take a radar signal of that frequency coming off a dish antenna and use it to modulate the intensity of a laser beam exiting a laser. You then send the beam a long distance, up to twenty or thirty miles, and by detecting it—i.e., using an optical-to-electrical converter, recover the original microwave signal. The old way of doing this involved sending the raw microwave signal in heavy copper pipes, or waveguides. These waveguides, in addition to their weight, were very lossy and would attentuate the signal in a few hundred feet. So you can see why this was a minor revolution in the business of sending information long distances. If you replace the microwave signal in my example by telephone or computer data, you have the basis of long distance optical fiber communication. Anyhow, there was an interest in using these new ways. There was a new kid on the block, a new game, but no source. So why didn't the two or three students who were graduating at that time and knew how to do it form a company? I think, DARPA even asked us to do that; DARPA told us that they'd support it. So I talked to two of the students. Actually, one was a postdoc—Nadav Bar-Chaim—from Israel and the other one was a graduate student, Israel Ury.

COHEN: Ury was from Israel, too?

YARIV: No, Israel Ury is an American, but a son of a rabbi [laughter], so he has a purely Hebrew name.

COHEN: And he's from Los Angeles?

YARIV: Yes. And he speaks fluent Hebrew. Interestingly, he has since been to Israel many times, but at the time I was surprised to hear a non-native speak such good Hebrew. The Israeli postdoc, Nadav Bar-Chaim, I see often at the Pasadena temple. And with Nadav and Israel we started ORTEL. "Or" means light. And "tel?" Do you know what "tel" means?

COHEN: A *tel* is a little hill.

YARIV: Also, in Greek it means "distance"—as in "telephony," "telepathy."

COHEN: So that was the beginning of the business. But of course you couldn't be head of the business; Caltech didn't allow that.

YARIV: No. Caltech then, and even today, doesn't allow a Caltech faculty member to have line responsibility. But there's no restriction on ownership or involvement in a company. So I never had a position in a company. I was chairman of the board and a consultant. [Tape is turned off]

AMNON YARIV

SESSION 3

December 1, 1999

Begin Tape 3, Side 1

YARIV: I'm holding this paper, "Phase Conjugate Optics and Real-Time Holography." [*IEEE Journal of Quantum Electronics*, QE-14: 9, September 1978, by Amnon Yariv] This paper is representative of the other area, which was a very active area of research in our group.

COHEN: Now, this other area is called—?

YARIV: It's classified under the general category of nonlinear optics. Nonlinear optics is the name reserved for a new field that was born after the invention of the laser and owes its existence to the laser. The word "nonlinear" has to do with the fact that the usual optical materials and phenomena are considered linear. This means that if you simultaneously pass two laser beams, either of the same wavelength or different wavelengths, through a piece of glass, they ignore each other. Each one behaves as if it were all by itself. But if the beams are intense enough—as can be the case with laser beams—and if some other conditions are met, then the beams can influence each other. As a matter of fact, they can sacrifice themselves, so to speak—commit suicide simultaneously and give birth to new light.

COHEN: Different from the two [original beams]?

YARIV: Yes, but it has some properties of both of them. It's a mathematical product. The first beam multiplied by the second.

COHEN: Not added, but multiplied?

YARIV: That's right. That's why it's nonlinear. They multiply each other. That means, for instance, that the frequency of the new beam is the sum of the frequencies of the original beams, meaning that the color changes. Oddly enough, where beams multiply each other their frequencies add. You add the colors, but you don't add wavelengths, you add frequencies. If there's information on one of them, like spatial or temporal modulation, that's also passed on to the new wave. This whole deal is known as nonlinear optics. So we have been involved in nonlinear optics probably since the late sixties or so. Phase conjugate optics, which is the title of this article and the name of the research project we started here, was a branch of nonlinear optics. And the way it happened is interesting, at least to me. While I was teaching a class at Caltech on quantum electronics—the physics of lasers—one day, I posed a problem to the class. And I think it's restated here somewhere. It was as follows: We can look through a window and see a tree, which is outside. Let's say you are in the living room looking outside on a garden and there's a tree. We see it. Now, we don't think, most of the time, that the picture—the rays of light that carry, or control, the information—has to move, or propagate, through the window. Here's the question: Suppose we take the window and make it much smaller and longer. You stretch it out and eventually you have a fiber, which is, let's say, a kilometer long. Can we now use that fiber to look at a tree that's a kilometer away? [The fiber is] like a window that is very long—even thousands of kilometers. We do it gradually. What happens to the picture? And I'm talking fundamentally, according to physics—not in practice. Do the laws of physics allow this? And if that's the case, can we transmit pictorial information in a fiber? The answer is no, you cannot do it. If you analyze how a fiber will propagate the pictorial information, you find out that basically the picture excites different modes of light in the fiber. Each mode propagates with its own velocity, which is different from that of the others. Because of that, the picture breaks up, like Humpty Dumpty. Just as a hydrogen atom has many energy levels—that is, quantum states—a fiber has different states, or modes, in which the light can be excited. These modes are excited at the input by the picture projected on the input face of the fiber, and this is how the picture—the light—propagates. Every optical waveguide has its unique modes—the Eigen, or proper, modes—and the picture excites those modes. And as they propagate they get out of step, since they each have a different velocity. So when you put them back together at the output, which your eye would do, they have lost their relative phase, which is necessary to reconstruct the picture. The picture is not smeared, it is not lost mathematically; it was just recoded into a different type of picture, but one that our eyes don't recognize. It's like translating from one language to another. If you don't know the new language, you have gibberish.

COHEN: So you're saying that it's still there but you can't see it.

YARIV: It's still there. The information wasn't lost, because the process I described is deterministic. It's not random; it's not like a vibration of grains of sand you can never get back. Everything is predictable. And the formula for reconstructing it is mathematically very simple. You take those modes of the picture that propagate faster than the others and slow them down. Imagine a bunch of horses running around a racetrack. After a few rounds, some horses are ahead and some are behind. Assuming that each horse keeps running at the same speed, you have a recipe now for regrouping them so that they will all fall in line again. What you do is you blow a whistle, which causes, by prior agreement, each horse to freeze where it is. And then you turn them around. The horse that was farthest ahead is now last, and the one that was last is first. And then you blow the whistle again, and they start running. The fast horse is now last, but it's still running faster, so it will catch up with the first one. And when it does, you figure all of them will have caught up at the same place.

COHEN: Now, when you gave your students this problem, you didn't tell them the scheme? They had to figure that out?

YARIV: Well, I told them what I told you. And I said, "What we need is a physical way of essentially reversing the horses and putting the fast horse back—penalizing it, handicapping it. Because it runs faster, now it's last." I knew the class could come up with the mathematical solution. And we came up with some kludgy solutions that worked under limited conditions. And then one day I had a "eureka" moment, and I realized that this field—nonlinear optics, which I just described—had the key. Remember, in [nonlinear optics] two optical fields can multiply each other. Essentially, we take the field that we want to time-reverse—

COHEN: It's called time reversal?

YARIV: It's time reversal, because mathematically it's like making the reel move backward. If you made a movie of the horses and played it backward, the horses would regroup again. So by multiplying the fields, one of the fields is time-reversed.

COHEN: Now, did the students like this kind of problem?

YARIV: Of course. It was a challenge. We couldn't solve it. I kept working on it, for half a year later or so. The students had gone on to other things. [Laughter] They had other pressures. This was a class; these were not my research students. We had the recipe for doing it, but how do you do it?

COHEN: So they solved it in whatever way they could?

YARIV: We couldn't solve it. It seemed like an impossible task, because when you excite the fiber, you really excite many thousands of those modes, and you have to do it for each one of them. You can't do it artificially with bolts and nuts or screws; it has to happen all at once. Anyhow, nonlinear optics does it. It's magic.

COHEN: So you figured that out by just thinking about it for the rest of the year?

YARIV: Well, it wasn't that it took a long time. If somebody had told me on day one, when I posed the problem to the class, "Use nonlinear optics," I would have come up with it. But the main break was to think of nonlinear optics as the place for the solution. For me personally, I need to absorb the mathematics of physical phenomena and then create mental visions of what the equations mean. You can see the waves doing their thing and multiplying each other. I've been thinking about these kinds of problems for many years and they've become part of me.

COHEN: So you have to know the mathematics and then you see this.

YARIV: You need to absorb. First, know the mathematics, and then absorb it and have billiard-ball pictures of what the mathematics means. Mathematics is usually good for checking on things—for checking intuition—but you don't invent with mathematics until you absorb it organically. Nobody sits and does mathematics and invents a transistor or a laser. You have a mental picture of a laser or a transistor or phase conjugate optics, which is really based on the absorbed mathematics, before you do it, and then you check the result with the mathematics.

COHEN: So the idea and the picture have to be first—

YARIV: But in complicated problem areas you can't have the idea without having sweated out the abstract mathematics. You have to think physically-mathematically. The two are really intermingled.

COHEN: You have to have this background in mathematics.

YARIV: That's right, absolutely. To get to the point where you can think that way, you have to pay your dues. You need to study a lot of formal mathematics and solve problems and apply it to a lot of physical problems. A lot of that happens in a good school.

COHEN: So you have this problem: Is it sort of in the back [of your mind] and you think about it even when you don't think you're thinking about it?

YARIV: It's there all the time. It could be there for, as I said, months at a time. And I think about it. Sometimes I'm not aware that I'm thinking about it. The mind keeps grinding at it and makes progress.

COHEN: By itself.

YARIV: Yes. [Laughter] Without your knowing it.

So anyhow, we came up with the solution. And the consequences were so amazing that we sat on them for a while before we came out with them. There were many other implications. Anyhow, it turns out that in Russia [Boris Ya.] Zel'dovich, for other reasons, also came up with what fundamentally was the same thing. As I said, my story was a class assignment of restoring pictures. [Laughter] He was trying to correct the quality of optically degraded laser beams. Now, you can see that there is a common denominator of correcting, or undoing, distortion. This has now become an established discipline in optics.

COHEN: Now, what happened? When you had the idea, you then had some good students who said that they'd like to work on this?

YARIV: Oh, yes, immediately. It's a credo with me that having good ideas is fun but having them and demonstrating them for the first time is a lot more fun. We had the lab and we had good students, so we were in a position to try out our ideas. As a result, we did a fair fraction of the major experiments that established the field during the first couple of years. Our first publication was in '76, [A. Yariv, "Three-dimensional pictorial transmission in optical fibers," *Appl. Phys. Lett.*, vol. 28, p. 88, 1976]. That paper came before we had a solution. That's posing the problem and giving the mathematical solution but not the physical solution.

COHEN: So what is your style? When you have a student come in, do you suggest a project?

YARIV: Yes, always. You can't force a student to work in an area, so you have to sell it to him. And most of the time the students are amenable.

COHEN: They probably come because they have some idea of what you're doing anyway.

YARIV: Most of the students really have no idea what they want to do. They have a vague idea that they'd like to get a degree in lasers or laser physics. And most of them are happy to have a project, a problem, because that's a difficult stage. Often you can rattle around for a year or so before finding a problem. Also it was at that time an exciting area; in a sense, it was new. Incidentally, as a small aside of interest, it had some connection with Star Wars—

COHEN: Yes, I was going to ask you about that.

YARIV: You see, you can correct for distortions of optical beams with this technique—like restoring the image. The Star Wars scenario involved shooting laser beams up through the atmosphere to destroy incoming ballistic missiles. And the atmosphere distorts the laser beams and drastically lowers their intensity. If you take a laser beam and aim it at the missile outside the atmosphere, by the time the beam emerges from the atmosphere it will be broken up and essentially useless, because the energy will be spread over a large area.

COHEN: So you're saying it would not have worked—the idea of Star Wars?

YARIV: Well, not simply as it is. But by using those techniques, you can regroup the energy, so to speak, and make it useful. Star Wars wouldn't work, and hasn't worked, for many, many other reasons. But the architects of Star Wars, those ill-fated [ideas], were aware of that problem. And one of the solutions they came up with was to use this technique for reconstituting the beam.

COHEN: Now, it's interesting. You wrote an article in *Engineering & Science*—1988, I believe—on Star Wars.

YARIV: Yes. ["Star Wars Technology—Will It Work," *Engineering & Science*, Winter 1988, pp. 29-26] I was a member of a committee of the American Physical Society which was constituted to look into and report on the scientific feasibility of Star Wars. And the end product of our committee was a report that appeared as an issue of the *Reviews of Modern Physics* ["Report to the Amer. Phys. Soc. of the Study Group on Science and Technology of Directed Energy Weapons," *Rev. Mod. Phys.*, 59, July 1987]. And I gave a Watson lecture and wrote this article, essentially summarizing the findings of the committee. But what I wanted to tell you is that for Star Wars, DoD [Department of Defense] considered using phase conjugate optics as one of the ways to overcome that particular problem. But Fran, my wife, was writing a novel based on science politics at a major defense laboratory, or aerospace laboratory, before the Star Wars incident. She wanted a story. So I suggested to her that the lab would come up with a proposal for using phase conjugate optics to shoot down missiles. And this was about two years before the scheme was actually discussed by DoD. She never published the book; she couldn't find a publisher. And I think it probably would have been very funny had the book appeared. A popular book, and then somebody pointing out that Star Wars got its idea from popular science fiction. [Laughter] Anyhow, it didn't happen that way.

COHEN: Well, too bad. A good scenario. So anyway, you continued then? You had students working on this?

YARIV: Yes, we worked in this field for maybe ten years or so. And this field is related to holography also—to optical data storage and recording—so we worked on that aspect of it.

Also, for doing that kind of experiment you need a special type of crystals. We eventually set up a crystal-growth facility to grow those crystals at Caltech, so it kept us busy.

COHEN: So you had two efforts going at the same time.

YARIV: Yes. We had maybe even three, but the third was a completely independent effort; students who did that were in their own group. We had seminars.

COHEN: Is it still going on?

YARIV: No. We stopped phase conjugate optics research work about two years ago.

COHEN: Why is that?

YARIV: We ran out of great ideas. The field of nonlinear optics is still plodding on in many places, but some of the great expectations in terms of practical applications didn't materialize and it seemed that the flow of great ideas has come to a trickle. For practical applications, phase conjugate optics was not efficient and we did not have the right materials. There were a number of very elegant ideas at the beginning, here and elsewhere. But I think in the last few years the field has kind of matured, or finished—but definitely matured—until the next breakthrough, if one comes. And also there was my decision to cut down on the size of my group, which had gotten to be quite big at that time. And I decided that rather than cut all across the board, like cutting each group by half—you know, you need critical mass in certain areas—that that was a natural candidate to retire.

COHEN: So this isn't one of the [areas of work] that went on into a company?

YARIV: No. Well, yes and no. As I said, there were the basic ideas of data storage, and a few of the students here from this area started a company. The technology is related to holograms, and they essentially made a hologram that Harold Zirin [professor of astrophysics, emeritus] used as a filter to photograph the sun—you know, the H-alpha lines, the red lines, that he uses. And according to Hal, they were better filters than any he had used before. [Laughter] It was kind of a side product. But that wasn't enough to keep them going, and they essentially changed direction and are now doing something else.

COHEN: But you didn't have anything to do with that particular company?

YARIV: Oh, yes, I'm involved with them.

COHEN: What is the name of that company?

YARIV: It's called Arroyo Optics.

COHEN: Where is it?

YARIV: In Santa Monica. And Arroyo really owes [its origin], in a convoluted way, to this effort.

COHEN: This is a going concern?

YARIV: Yes, they are a company of about thirty-five people now.

COHEN: And they make holograms?

YARIV: No, they don't make holograms; they started by making holograms. Well, do you know what a hologram is, fundamentally? You know how you make it. But physically, if you took a hologram and looked inside the material in which you wrote the hologram, you would see a sinusoidal corrugation of some property, something wavy that goes like this. That something could be the silver density, if you make a simple hologram. Or if you make it in a volume, in a crystal, it's a periodic modulation of the density of the charge. A hologram is a sinusoidal perturbation frozen in time and space. And those things also act as filters. Did we talk at all about wavelength division multiplexing—transmitting many optical beams, each with a different wavelength, in a single fiber?

COHEN: Yes. You talked about a student who found a way so it wouldn't lose energy.

YARIV: OK. The main challenge is that you have a hundred laser beams, let's say, propagating in a fiber, each carrying its own information. If you do it, you can increase the information-carrying capacity of the fiber by the number of beams that you use. If you use thirty beams, you have increased the capacity by thirty. But a prerequisite to using thirty laser beams is the ability to put them into the fiber and drop them—that is, bring them out one at a time—wherever you want to. And those are filters; those filters are really intellectually the continuation.... They are holograms in a fiber.

COHEN: I see. So is that what the company is doing?

YARIV: That's right, yes.

COHEN: They are making these special filters for fiber optics.

YARIV: For the Internet.

COHEN: Right, OK.

YARIV: That component is probably today, with one or two others, the key enabling device for optical-fiber communication.

COHEN: Oh. So that's a very big thing.

YARIV: Potentially, yes.

COHEN: So how involved are you with this company? Are you on the board?

YARIV: Yes. I consult with them technically. I hold their hand at crucial times. But I have no line responsibility.

COHEN: That's your Friday. That's how come you're never available on Fridays.

YARIV: Never on Friday. Friday I'm—

COHEN: Out in the field.

YARIV: Yes, solving practical problems.

COHEN: OK. So then you went on, after you cut off this aspect of your work.

YARIV: At that point we concentrated, again, on lasers. We had always worked with semiconductor lasers, and still do. Those are the fundamental issues.

COHEN: That's the meat and potatoes of your lab.

YARIV: Yes. There are the fundamental issues of noise: How quiet can they be? How pure can they be? And we have always worked on that. We talked, for instance, about light propagating in fibers and loss of picture definition, or information. The physics of the propagation of light in fibers is very rich. A lot of things happen that are fundamental, and all of them have an impact on the ability of the fiber to carry a large amount of data. Some of those things really are bottlenecks that you need to understand and solve if you want to shove more information into a fiber.

COHEN: Yes. So that's the sort of thing you keep working on?

YARIV: That's a major, major issue. And a completely new area is one that we started about three years ago, in collaboration with Professor Axel Scherer. His specialty is nanofabrication—making very small structures, and etching and drilling on a submicroscopic scale. He's really one of the world's experts in this field.

COHEN: Miniaturization?

YARIV: Well, it's more than miniaturization. The "nano" maybe comes from the word "nanometer," which is 10 angstroms. So things are done on scales of nanometers.

COHEN: OK. Is this where they make a molecule, or an atom, as an engine, or something like that? I think that's the sort of thing that Jeff Kimble does.

YARIV: No. To make molecules as engines maybe is more what a chemist would do. You know, some molecules are engines. Jeff does something else: quantum optics. He has single atoms interacting with light in a single molecule. The specialty of Axel Scherer is manipulating materials, mostly solid materials. Axel was hired in electrical engineering, but since then he has been adopted by applied physics and physics, because he is in demand. And I'd say probably I'm the greatest beneficiary, because we work probably closer [than most]. We have both received a grant from the air force to look at artificial periodic optical materials. The area is known as photonic band-gap materials. Maybe I should give a little explanation. You know that semiconductors are different from metals; they are different from insulators. What characterizes them is that they have a gap, an energy gap. Have you heard that term?

COHEN: No, but I should know it, I suppose.

YARIV: OK. Well, you know that electrons have energies? And to find those energies is the main purpose of quantum mechanics. You need to solve the Schrödinger equation, and [then] you find [the] allowed energy levels. It turns out that if the electrons find themselves inside a periodic structure, like a crystal, because of the periodicity there are regions—bands of energy—which cannot be occupied by electrons. These regions of energy are *verboten*—no admittance. We call them "forbidden energy gaps," and they are the direct consequence of the fact that the electron is actually a wave and the crystal is periodic. So waves propagating in periodic crystals have these forbidden gaps in which they cannot exist. That's the basis of semiconductors.

COHEN: OK.

YARIV: In a semiconductor, you have the electrons and holes—you have probably heard the term "Shockley transistor." And they are separated by an energy gap. The electrons just above the gap are called conduction electrons, and those below are called valence electrons. And that's how all semiconductor devices—transistors—work. So the main thing to remember here is that the gap is a result of the periodicity of the medium.

COHEN: So for different elements, it's going to be different?

YARIV: That's right. That's why every material has different energy gaps. Semiconductor lasers work by electrons jumping across the gap, from the top of it to the bottom—from the conduction band to empty states in the valence band—and giving up the difference in energy, because they have nowhere in the middle, where the gap is, to go. And they give up the energy as light; that's how lasers work. Anyhow, electrons have wavelengths of the order of angstroms, and crystals have [similar] periodicities; the distance of the sodium atoms and the chlorine atoms in sodium chloride salt is roughly 4 or 5 angstroms. So the interatomic distances and the wavelengths are compatible. If you go to the optical regime, the wavelength of light—let's say visible light—is around 1 micron. So a professor at UCLA by the name of Eli Yablonovitch came up, about ten years ago, with the idea that if you could make an optical material periodic in some fashion—render it periodic in space—it should start manifesting phenomena similar to what electrons do in crystals, like energy gaps and so on. And that area has become known as photonic crystals—those materials. The students make them by drilling holes in a periodic pattern inside some materials. And using it, we at Caltech have made a whole bunch of new devices—the first in the world—including the world's smallest laser, which was published a few months ago in *Science* magazine [Painter, O., R. K. Lee, A. Scherer, A. Yariv, J. D. O'Brien. P. D. Dapkus, and I. Kim, "Two-dimensional photonic band-gap defect mode laser," *Science,* 284, June 11, 1999, pp. 1819-1821]. They are very, very small lasers. It turns out that light whose frequency—photon energy—is in the forbidden gap cannot penetrate the material; or if it's generated in the middle of the material, it cannot escape—it's confined. We call these light traps "optical resonators." And confinement—resonators—is always a prerequisite for making a laser. If you trap excited atoms or electrons, the time they spend in the excited state is very different in these materials than in the bulk or vacuum. We can make it last longer or shorter times, and that is very basic. We are pursuing this.

COHEN: I see. You have students working on this?

YARIV: Students of mine and of Axel Scherer's have been working on it now for about three years, and are even beginning to get out. So this new direction of micro-optics—manipulation and guiding of light really on a nanoscale—

COHEN: This is something new for you then, Amnon, because you have not really worked with other professors before.

YARIV: I've never worked with other professors, but now I do. It fits my stage in life. You know, I don't want to run a big group and maintain the huge infrastructure necessary to do it, so—

COHEN: So this lets you intellectually be involved in these things.

YARIV: Yes.

COHEN: I see. So that's going along. And then there's a third company I had listed for some reason. In Santa Clara.

YARIV: Arithmos. That's another company that was founded by a student here. I had a student who did a Carver Mead type of PhD project, meaning electronic. And how he did it was kind of a long story. But to make a long story short, the student did not work in the traditional areas of my group. He started to, but then we decided to pursue a different direction. And before we realized it, he was designing electronic circuits.

COHEN: Which isn't something you do?

YARIV: It's something we don't do. And we decided, together with Carver Mead [Moore Professor of Engineering and Applied Science], that he could mingle with Carver Mead's students but get the PhD from our group, because there was an optical element involved in the research, too. And Caltech is flexible. So he eventually got a PhD in electronics, and he was designing dedicated electronic chips. When he left here, he founded a company. He was also extremely talented. His name is Chuck Neugebauer.

COHEN: Neugebauer?

YARIV: Not related to our Neugebauer [Gerry Neugebauer, Millikan Professor of Physics, emeritus]. Anyhow, he founded a company in Santa Clara, with which I'm not involved. But it's an outgrowth—and as we speak, I think they are being sold to a French company.

COHEN: I see. OK. Well, that's the next step, I guess.

YARIV: Yes. But if you wanted to count companies spawned directly or indirectly from our group—

COHEN: You would count that one.

YARIV: Yes. Another one is a company, rather large and doing very well, which was started by two postdocs in the group—again, without my involvement. And that has become a sizable company.

COHEN: Which company is that?

YARIV: It's called MRV.

COHEN: And where is that located?

YARIV: That's in Chatsworth. They're a well-known company, and they are growing. The postdocs were [Shlomo] Margalit and Zeev Rav Noy.

COHEN: Was that the Margalit who smoked so many cigarettes and solved one of your original problems? I remember you talking about him. You said he was brilliant.

YARIV: He was very brilliant. He's still brilliant. His son, incidentally, got his BS at Caltech. So we take credit indirectly for that company, too. What they did when they started the company was exactly what they did here; they made lasers.

COHEN: You know, when you said that this very good idea came to you while you were teaching—you obviously like to teach.

YARIV: Well, teaching to me is like the cod liver oil that our mothers used to give us—it's good for you [laughter], whether you like it or not. I love teaching, but at Caltech we are also very busy doing research. And teaching always obviously—

COHEN: Comes at the wrong times?

YARIV: Yes. You know, sometimes you are very busy, you don't have time to prepare a lecture. But as a working scientist, when you run into a problem, you need to study the relevant science, the relevant theory. And you study until you feel you understand it fairly well, and you stop. Suppose you need to teach that same subject matter to a class. You will go a lot further and spend more time, because you have to be able to explain the material to the bright students, and the result is that you'll understand it on a deeper level. That's crucial. You become a better scientist as a result; I think that teaching forces you to understand the material on a much deeper level, and then that turns out to be crucial for research, for progress.

COHEN: So you think it's valuable even though you don't always feel like doing it?

YARIV: I think it's absolutely necessary.

COHEN: But, on the other hand, committee work you don't think of as necessary.

YARIV: No, it's absolutely necessary, too. I've served on many committees, but mostly they were ad-hoc committees—not standing committees but committees for a purpose.

COHEN: What sort of committees?

YARIV: Well, the LIGO committee, appointment committees, search committees.

COHEN: Now, the LIGO project has been so controversial.

YARIV: Yes.

COHEN: What do you think about it? Do you think it's going to work?

YARIV: I think there is a chance that it will work. Like all research, it's not guaranteed. I think it's a worthwhile endeavor, and we're learning a lot of other good things along the way, even if it doesn't work. But if it works, the payoff is so fantastic that I'm very much for it.

COHEN: But you think that just for the learning process, it's good?

YARIV: Oh, yes. They're developing various disciplines and technologies: vacuum technologies, optical stabilization, noise removal. They need to quiet their instruments so that they can detect the very basic—

COHEN: So as a scientific endeavor, it's good. And it belongs at a university? That was also one of the—

YARIV: Oh, who else would do it? Of course, a national lab could do it, but I think it belongs at a university, because there are a lot of interesting basic problems. I think the intellectual fervor that surrounds it is good for a university. I think it's good for us.

COHEN: Were you in any way involved in all the controversy?

YARIV: You know, the LIGO committee [I served on] was formed during the controversy and for the purpose of resolving it. The main idea was to try and recommend a course of action. Remember, there was friction between [Ronald W. P.] Drever [professor of physics] and Robbie [Rochus E.] Vogt [Avery Distinguished Service Professor and professor of physics]. And clearly you needed objective outsiders—well, insiders at Caltech, but outsiders in the sense of not being directly associated with the project. The chairman was from JPL [Lew Allen].

COHEN: Did you find that [committee work] interesting, or just very difficult?

YARIV: It was very interesting, because we really got exposed to all the work. [Tape ends]

Begin Tape 3, Side 2

YARIV: Not much—a couple hours a week. I forget how often we met.

COHEN: So in some sense you were detached from the ferment. That is, one group felt that Drever wasn't getting what was good for him, and the other group felt they had to get rid of Drever. There was so much emotion.

YARIV: Oh, yes. Drever really was the intellectual father of the whole [LIGO] idea. And probably some of his ideas were the key for what was done and is done today, like the recirculation of power and so on. But Drever is a pure scientist, and the thing has grown—especially when NSF [National Science Foundation] money started coming in—to a point where it really had to be run like a business, with schedules and commitments. I think that was the basic philosophical clash. What it really meant was that Drever was going to lose control over his own baby, and he put up a fight [laughter], as any good mother would.

COHEN: Well, I think the problem was more how it was done than what was done.

YARIV: That's right. I assume that some of the people involved weren't the greatest tacticians—in the sense of "tact," not "tactics." It could have been done better. But I think Caltech came up eventually with—

COHEN: A good solution.

YARIV: It was good in that the storm seems to have subsided and the work resumed.

COHEN: Right. So you were on that committee, but it was ad-hoc. And then you've been on some national committees, for your professional societies.

YARIV: Yes. You know, the usual stuff, running conferences and meetings. But until about two years ago, I had a group of eighteen or nineteen graduate students and three or four postdocs and a couple of engineers—a group of maybe twenty-five people. You not only have to be involved scientifically, you have to feed them and clothe them. [Laughter] And go to Washington and get money for them. That took a lot of time. I really couldn't do that and be involved in committees.

COHEN: And then, of course, you had a professorship early on. You had the Myers Professorship [of Electrical Engineering], but you have another professorship now [Summerfield Professor of Applied Physics]. Why did you go from one to another?

YARIV: They took the chair away from me and gave me another chair. The Thomas G. Myers Professorship, the original one, was an electrical engineering professorship. And then Caltech got money for a professorship in applied physics.

COHEN: That was the Summerfield?

YARIV: Yes, the new one. And they felt, rightly, that they needed to give a professorship to Demetri Psaltis. He had become distinguished enough, in the meantime, to deserve a professorship. Now, they could not give the new professorship to Demetri, because the new professorship was in applied physics and Demetri was in EE. But I had an applied physics professorship.

COHEN: I see, OK.

YARIV: So it was musical chairs. Basically they took, with my permission, my [Myers] professorship and my chair and gave it to him and I got the new one.

COHEN: Very good. I'm just looking at some of your awards and honors here. Of course, you were elected to the National Academy of Engineering [1976] and then the National Academy of Sciences [1991] quite a while ago.

YARIV: Yes.

COHEN: Do you ever serve on any academy committees?

YARIV: No. [Laughter] When I retire I will. [Laughter] There really isn't enough time. I also like to hike and play the piano.

COHEN: And your travels are usually to Israel. Coming back to your travels, I notice that Japan played a big part in that.

YARIV: Yes. Well, our main impact on the real world—meaning not the world of ideas but the worlds of industry and technology—has been in optoelectronics and devices related to optical-fiber communication, like lasers et cetera. And the Japanese were, from the very beginning, probably the leaders in the field. We had a continuous stream, until very recently, of Japanese postdocs, and because of the involvement of Japan many of the major meetings in the field were held in Japan. The center of gravity has shifted back to the US, but for many years it was Japan.

COHEN: Now, did you have any problems with security? Because I've heard stories about Japanese people coming in and taking information from labs in not such an ethical way.

YARIV: Well, no. We always had Japanese visitors, but I don't think they ever took anything unethically. We were aware of the fact that clearly they were around and saw and learned. Occasionally I would ask not only them but everybody else—I'd say, "Look, this is a new area and we're going to apply for patents, and we don't want it advertised until the paper comes out." But we never singled out the Japanese. You will recall that the distributed-feedback laser, which we can import commercially, was taken back to Japan by our postdoc. But it wasn't done behind our back.

COHEN: You knew that it was going on?

YARIV: Yes. We even collaborated with them at the Hitachi Labs. If it weren't for Hitachi, the project would have died. Anyhow, I never had problems with that.

COHEN: OK. So you've been to Japan many times.

YARIV: Yes.

COHEN: Is that one of your languages?

YARIV: No. It's very difficult. The Japanese tell me that they've never met a foreigner, or have hardly ever met a foreigner, who can speak Japanese fluently. And you know, to me a language is an all-or-nothing proposition. I think learning a language so that you can say "Thank you" is not good enough. You need to be able to use it—read it and speak it correctly. And I didn't think I could make this commitment to Japanese.

COHEN: So looking back at all of this, being at Caltech all these years and doing all this wonderful work, what do you think?

YARIV: A great place to work. It's been a great experience. I would do it again. [Laughter] I'm still doing it. You know, nice colleagues, nice physical set-up.

COHEN: Mountains to walk in.

YARIV: Mountains nearby, which are more and more visible. The smog has been getting better. Probably the number-one asset is the students here. That's our raw material—the students.

COHEN: Right. Is there anything else you'd like to say?

YARIV: I think we've covered it all. [Tape is turned off]