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JOHN MADEY: A SHORT HISTORY OF MY FRIEND AND COLLEAGUE

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Figure 1: John Madey (1943-2016) in his Hawaii Laboratory.

BRIEF HISTORY AT STANFORD UNIVERSITY

I thank the organizing committee for inviting me to share with you some stories of my friend and colleague John Madey, who passed away on July 2016 in Honolulu, Hawaii.

I will first summarize to you the early history of John Madey's FEL at Stanford University. Then, I will try to briefly relate to you about our join work at the University of Hawaii. Lastly, I will share with you some final thoughts on John' achievements.

I met John Madey in 1973 at Stanford University right after he and I received our respective Ph. D degrees in Physics. He from Stanford University and I from the University of Wisconsin in Madison. It was through a connection between Professors Alan Schwettman and Arthur Schawlow of Stanford University with my major professor William Yen, from the University of Wisconsin, that I was hired to assist John Madey in the demonstration of his SBR laser. Perhaps my experience with experimental vacuum synchrotron radiation spectroscopy contributed to their hiring decision.

Before arriving at SU, John's proposal goal to show "Stimulated Bremsstrahlung Radiation" had been already funded by the US Air Force Office for Scientific Research (AFSOR). Instead of SBR, J. Madey later coined the acronym FEL (Free Electron Laser) to describe the device.

After meeting him in 1973, it did not take long for me to recognize the genius character of John Madey. During an early visit to his house in Palo Alto, I discovered that most of his house was filled with old radio electronic equipment. I then learned that John and his brother Jules had been actively involved in ham radio communications since 1956. As is well known now, when John was 13 and Jules was 16, they began relaying communications from the south pole to families and friends in the United States. I then realized that before his interest in the FEL came about, John had already accumulated a vast experience in the field of electronic devices, including his latest electronics accomplishment. It was digital communication equipment that allowed John, in Palo Alto, to communicate with his older brother Jules, in Marin County, by means of two very old teletype machines. It was a major achievement because at that time internet communication was not invented.

I remember that in 1973 there were not many scientists, including some professors at Stanford who believed that John's FEL would work. As described in his original publication [1], his physical interpretation of EM field amplification occurred because during electron radiation inside the static undulator field, the electron energy recoil can favor photon emission process over photon absorption. His quantum calculation of FEL gain was made in terms of photon energy $\hbar\omega$. I recall clearly how in one of John's presentations of his theory of the FEL to the Physics department, professors Felix Bloch and Arthur Schawlow pointed out the fact that in John's gain formula calculation $\hbar$ mysteriously disappeared from the equation. Despite of their objection, I was quite impressed with John's valiant and intelligent defense of his theory, considering that the objections were made by Nobel Laureates in physics.

As it turned out, John's gain equation was correct and his objectors were also correct because, as we know now, quantum electrodynamics is not totally needed to explain the gain result. The theory of FEL can be satisfactorily explained in terms of classical electrodynamics.

Because of Stanford University rules professor Alan Schwettman became the principal investigator of the FEL program and consequently our boss. As director of the Superconducting Acceleration (SCA) program, he allowed us the use of the SCA in the FEL program. After my arrival at Stanford University, Alan hired Todd Smith to run the SCA. Consequently, the three of us (John, Todd and I) were charged with the responsibility of implementing the FEL program in 1973.

The Stanford FEL program was divided into three major experimental subprograms that included: (1) the electron beam system, (2) the magnetic undulator and the (3) the optics system. Todd was responsible for the electron beam, John and I were responsible for the construction and testing of the magnetic undulator and I was responsible for the optics and signal diagnostic system.

Two 5.2-m long superconducting helical magnetic undulator were constructed for the experiment. The first undulator was wound with superconducting wire by means of a semi-automatic machine that laid a single wire along helical grooves milled on an aluminum mandrel. Unfortunately, this undulator was severely damaged because, when first energized at low temperature, an electrical short developed between the wire winding and the aluminum mandrel. This problem was eliminated in the second undulator by replacing the helical metal mandrel with a plastic one. Before potting the undulator wires, a 7-m long, 12-mm diameter copper vacuum tube was inserted along the axis of the undulator. With an inside diameter of 10 mm the copper tube served as a vacuum beamline designed to transport the electron beam and to also guide the optical beam. Low temperature testing of the new undulator was quite successful.

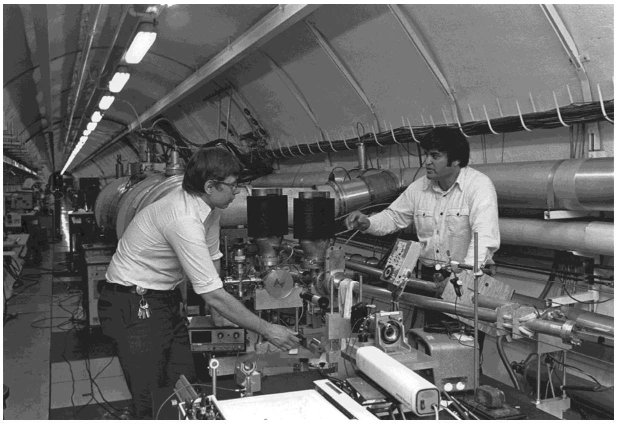

Figure 2: John Madey and Luis Elias working inside the SCA tunnel with the FEL equipment (1995).

In 1975, two years after the start of the project, the first test of FEL laser amplification was obtained using a pulsed Molectron CO_2 laser. Running of the SCA was very costly matter. Each FEL run lasted for only a few days due to the lack of sufficient FEL financial resources. We had to work day and night to test the FEL as a light amplifier. After two or three runs we finally obtained good data on the FEL gain.

Gain was observed for optical radiation at 10.6 μm due to stimulated radiation by a relativistic electron beam in a constant spatially periodic transverse magnetic field. A gain of 7% per pass was obtained. The detail of the results was published in the following PSL article [2].

Although John's FEL gain was demonstrated at 10.6 μm. A JASON committee, was appointed by the government in 1976 to evaluate the FEL usefulness to the Department of Defense. The JASON committee central finding was that the FEL gain was too small. Perhaps their negative reaction took place because John, because of engineering background, used to described the power gain of the FEL in decibels units. In decibels, the gain of the FEL was only 0.3 dB. Compared to the gain of more than 10 dB observed in commercial electron devices, such as microwave tubes, the FEL gain is indeed quite small. The findings by the JASON committee had the negative effect of putting in danger the continuity of FEL program funding by the AFOSR. In fact, for a period of one or two months, John used his own money to pay for my salary. I was not aware of John's generous gesture until we met again in Hawaii.

To counteract the negative aspects of the JASON committed report, John and I agreed that we needed to accelerate the next phase of the FEL program, that is we needed to show FEL oscillations without delay.

To show FEL oscillations at 10.6 μm, the plan was to install spherical vacuum mirrors, separated by about 12 m, on each end of the undulator amplifier. Because of the length of copper tube (7 m), it was not possible to establish a pure TEM_{00} along the whole length of the copper tube.

We decided that our best chance was to transport the 10.6 μm guided mode along the copper tube. Hence, the radius of curvature of the mirrors were chosen in so that a TEM_{00} waist was focused at each end of the undulator copper tube. The idea was to match efficiently the TEM_{00} mode to a EH_{11}. This is dielectric mode, it is the lowest loss mode that can be transmitted along a copper waveguide because, at the CO_2 laser frequency, the copper surface behaves less as a metal and more as a dielectric. The estimated theoretical oscillator loss was about 2% per pass.

Unfortunately, as hard as we tried, we could not force to operate the FEL above threshold at 10.6 μm. After examining carefully, the inside of the copper tube, we discovered the existence of a mechanical deformation inside the pipe. We concluded that the kink in the pipe increased optical losses beyond what was required to operate the FEL above gain threshold.

After many discussions, I convinced John that we should increase the electron energy so that a higher frequency pure TEM_{00} could clear the copper waveguide and thus diminish the losses contributed by the copper waveguide. John agreed to the suggestion provided we could accurately measure the actual optical losses of the resonator before using the electron beam. With the help of Jerry Ramian we design and constructed a pulsed intracavity helium-neon gas amplifier operating at a wavelength of 3.39 mm. When installed inside the FEL resonator, the decay time of the TEM_{00} mode showed below 2% resonator optical losses. Encouraged by this result, we tested the operation of the FEL at 3.39 μm at the end of 1976. Almost immediately the FEL operated as an oscillator. The result was published in a PRL letter [3].

It is an underestimation to say that we were all overjoyed by the results obtained. To show his enthusiasm, the next day after the FEL operated as an oscillator, John brought down to the laboratory a case of champagne to celebrate the success of our efforts. For the benefit of those at Stanford who were not convinced that John's FEL experiment would work, we transported the output laser beam along a 24-m path out of the experimental area and showed the spot made by the beam on a thermal foil located outside lab. Many people, including professors, scientists and students came to see the spot image. As one of the observers, I clearly remember professor Schawlow saying “Oh, this actually works!”

It took us more than a couple of weeks to realize the full implication of the FEL results. Our euphoric feelings were tempered by our paranoidal thoughts that we were being watched by interested government and/or industrial agencies who wanted to misappropriate our experimental findings. Thankfully, after a couple of weeks, those feelings disappeared.

Our first contact with international scientist came about immediately after we failed to present our FEL results at the 1975 Quantum Electronics Conference in Washington, DC. My good friends Alberto Renieri and Pino Dattoli, from the Enrico Fermi Laboratory in Frascati, Italy, were present at the conference and traveled without delay to Stanford University to learn the details of the FEL experiment. We were informed that most of the participants at the conference had protested our absence noisily by stomping loudly their feet on the floor. We explained to them that we could not travel to Washington because we were in the middle of an expensive FEL run.

Later that month, my other good friend from Israel Avi Gover, who was finishing his Doctoral degree at the California Institute of California, came to Stanford to congratulate us for our FEL success. We were all delighted to meet and discuss the FEL with all our distinguished visitors.

Our first serious discussion of FEL applications took place at the Los Alamos National Laboratory in 1977. The group working with the separation of U-235 from the naturally occurring U-238 were doing it with a diode laser that generated only 6 milliwatts of power. When they heard that our FEL generated megawatts of power, we were immediately invited to present our results at LANL. Because I was not then a US citizen, the presentation was moved to the library of the lab. After the presentation, our colleagues were quite serious with the request to move the FEL equipment from Stanford University to their laboratory. John explained that their request was not possible to implement. Instead he suggested that LANL should build their own FEL, which they later did.

After the FEL oscillator experiment was completed John became interested in increasing the average power of the FEL. The use of an electron storage ring appeared then to be an appropriate device where an FEL could operate with large average power output. We all knew that during FEL amplification the energy spread of the incoming electron beam increased. John was hoping that the side of the FEL resonance curve that produces gain behaves like a force that should damp electron energy oscillations. Our computer simulations gave us the opposite result when the whole resonance curve is introduced into the simulations. At that time, John was not a computer guy. He dependent on his HP programmable calculator to carry out his simulations.

Using theoretical considerations (Liouville's theorem) Alberto Renieri confirmed that continuous energy damping could not take place in a an electron storage ring FEL.

Later, John and David Deacon collaborated with their French colleagues at the ACO electron storage ring in Orsay to test the operation of an FEL. The results confirmed that Ranieri was correct in his prediction of low average power FEL operation in an electron storage ring.

Before I moved to the University of California at Santa Barbara in 1978, I visited Richard Hechtel at nearby Litton Industries in San Carlos, CA. As a consultant, Richard was designing a depressed electron collector for an electrostatic accelerator FEL that I wanted to construct in Santa Barbara. I was explaining to him how we demonstrated FEL oscillations at Stanford University. Richard commented that the FEL appeared to like commercial electron devices. By then I had read about the Ubitron device. Richard reacted immediately and told me to come with him and meet the inventor of such a tube. It was a great pleasure to meet Robert M. Phillips. He was delighted to learn that the FEL amplifier operated very much like an extremely high voltage Ubitron tube.

At the end of my term at Stanford University, John Madey was awarded the First International FEL prize. He could not go to Jerusalem, so, he asked me to receive the accolade on his behalf. Of course, I was honored to do it.

JOHN AND MYSELF AT THE UNIVERSITY OF HAWAII IN MANOA

After nearly 7 years working with John at Stanford University, I was invited by the Physics Department of the University of California in Santa Barbara to construct and operate a far infrared FEL that could be used to study the physics of condensed mater. Eventually John moved to Duke University in Durham, North Carolina where he continued with the further developments of FELs.

Subsequently, after developing a compact far-infrared FEL at the University of Florida in Orlando, I was invited to join the faculty of Physics Department at the University of Hawaii in Manoa. I brought to Honolulu the compact far-infrared FEL. John was already there when I arrived. He offered me laboratory space inside his FEL laboratory for my FEL. Regrettably, because of the thick concrete radiation wall requirements required by the accelerators it was not possible to install my FEL inside his laboratory. Due to the high-cost of construction in Hawaii, the university did not have the funds to construct a separate far-infrared laboratory. The final disposition of my compact FEL was to ship it to the CBPF (Brazilian Center for Physics Research) located in Rio de Janeiro.

In Hawaii, John and I worked closely, for nearly 14 years in support of the Department of Defense focus on remote detection of IEDs with lasers. We also carried out discussions and calculations of EM radiation resistance problems.

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JOHN MADEY: SOME OF HIS ACHIEVEMENTS

It may sound simplistic but I believe that John Madey showed us that he was a unique genius whose life was dedicated to enriching our understanding of electrodynamics and to advance technology for the benefit of humankind. His work with ham radio and his extraordinary contribution to the field of FELs and its applications to medicine are mere examples of his exemplary good character. The importance of John's scientific impact to science was stressed by the APS's selection of the two PRL publications, [2] and [3], as the most important scientific contribution of each of the years 1976 and 1976. For his scientific work John was awarded many prizes and accolades, including the *Stuart Ballantine Medal* from The Franklin Institute in 1989 and the *Robert R. Wilson Prize for Achievement in the Physics of Particle Accelerators* by the American Physical Society.

To continue with his magic scientific predictions, prepared an experimental proposal aimed at demonstrating that advanced solutions of Maxwell's equation do exist. Before he passed away, he explained to me how he and his brother Jules were ready to demonstrate instantaneous EM communication between two points in space through the detection of near-field advanced waves. As proof of the seriousness of such an experiment, they prepared a patent disclosure describing the invention. If they are right, one cannot imagine the technological impact that their discovery will have on our human society. It is up to the University of Hawaii to request a patent.

An image that is always present in my mind is the picture of John Madey permanently dressed in his black shoes, black trousers, white shirt and a blue sweater whose right side had a hole on his right side that allowed him to have direct access to his numerous keys hanging from his belt. I assumed that the hole on the sweater developed because of its daily usage. However, in one of our trips to Italy John purchased a brand new blue sweater. The next day, to my surprise, the hole appeared freshly cut.

Another Image of John was his driving an old (1960?) rusted car to work. When I asked him about buying a new car he remarked that he himself could tune up the old clunker faster and more efficiently than a new computerized engine. To compensate for the old car, John was the pride owner of two Alfa Romeo cars. He would ride them on weekends. He told me that the only inconvenience with these cars is that he had to purchase their park plugs in Italy, the ones sold in the US did not work as well.

I remember Professor Schawlow telling me the story that that he and Professor Charles Townes had prepared a list of the ten most common applications of conventional lasers. He told me that none of their predictions were realize. Apparently, the most common commercial application of lasers is to digitally scan the price of products in supermarkets. John and I had a similar list for the FEL. None of our predictions came true. We were aware that, except for the absence of efficient mirror reflectivity FEL operation in the X-region was possible. SASE FEL radiation was not considered by us at the time. We are now all delighted by the success demonstrated by SASE FELs around the world. I am sure that the next speaker will elaborate on the important contribution that my good friend Rodolfo Bonifacio made to the theory of SASE radiation

I had the great honor of working with John Madey for more than twenty years. As a scientist, I owe him what I have accomplished, as a person I loved him like a brother. The fact that you are all here proves that John Madey also has a significant impacted in so many careers. I miss him greatly.

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