An interview with Gérard Mourou

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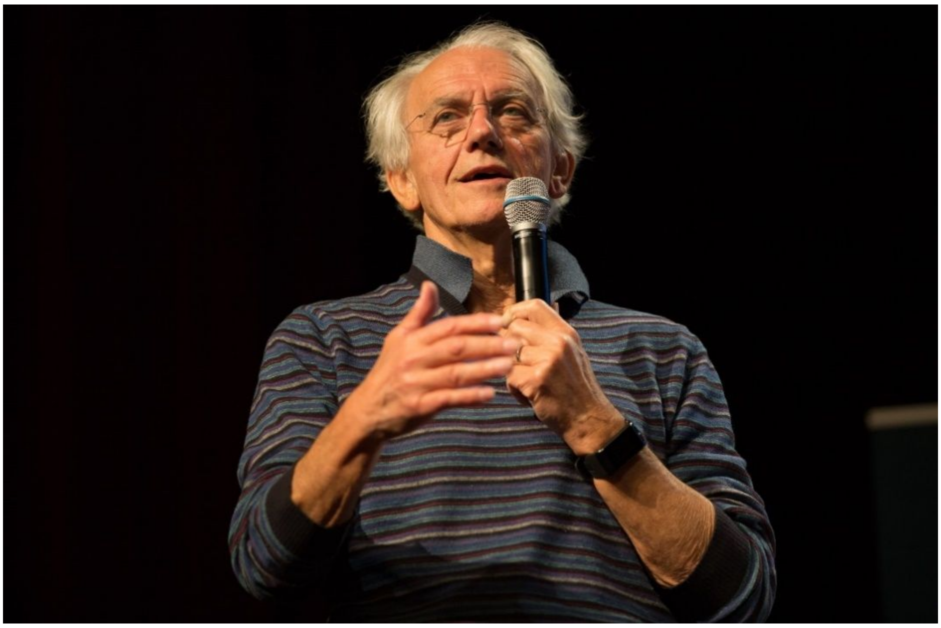

Gérard Mourou ©Ecole polytechnique

Gérard Mourou received his PhD from Pierre and Marie Curie University in 1973. He and his student Donna Strickland co-invented chirped pulse amplification (CPA) technology and shared the 2018 Nobel Prize in Physics. This technology made it possible to apply ultrafast lasers to many new areas such as eye surgery, precision manufacturing, particle physics and nuclear fusion. Gérard Mourou is the founding Director of the Center for Ultrafast Optical Science (CUOS) at the University of Michigan and the initiator of the Extreme Light Infrastructure (ELI) in Europe.

Guoqing Chang: How did you get interested in ultrafast science at your early career?

Gérard Mourou: After receiving my PhD, I spent one year at the University of California at San Diego (UCSD) on a postdoctoral project under the guidance of Professor Michael Malley. During this period, I used a picosecond resolution signal testing system to measure the motion of atoms or molecules in the liquid. I was fascinated by this measurement system and found such experiments very elegant. Therefore, I put a lot of effort into the development of this system. At that time, I took advantage of the birefringence properties of CS_2 in the infrared region to design a high-speed shutter (now called a Duguay shutter) to take snapshots of moving molecules.

Guoqing Chang: In 1977, you moved to the United States and became a professor at the Institute of Optics of the University of Rochester. During working at the Institute, you demonstrated several groundbreaking technologies in the field of ultrafast science including the Nobel prize winning technology—chirped pulse amplification (CPA). At that time, what motivated you to pursue laser pulses with high peak power?

Gérard Mourou: I went to the Laboratory for Laser Energetics (LLE) at the University of Rochester to study laser fusion. In this study, we needed to develop a high-speed streak camera, in which the trigger signal determined the timing and measurement accuracy. Later, my first graduate student, Wayne Knox, and I invented a new type of trigger based on laser pulses with minimal single-shot jitter, which was successfully used in the laser fusion research. Since then, I have been fully engaged in the field of ultrafast optics. I was always very interested in short laser pulses, because it has the potential of generating an enormous power in a very, very short time. I was fascinated by the fact that a high-power laser pulse, which is 10 times the power of a nuclear power plant, could be created just by compressing the pulses. In addition, this interest was also closely related to the laser fusion I was working on at that time, and I knew that ultra-high power laser pulses were very useful in fields such as extreme plasma physics.

Guoqing Chang: In the first CPA demonstration, you and Donna Strickland employed optical fiber as the stretcher and a Treacy grating pair as the compressor, but this stretcher-compressor is not a perfect match. How did you find that the Martinez grating pair constitutes a stretcher that perfectly matches the Treacy compressor?

Gérard Mourou: We demonstrated the CPA concept in 1985, which produced ultrashort pulses with millijoule level pulse energy. In this rudimentary demonstration, we used the optical fiber stretcher with positive dispersion, which could not match Treacy grating compressor in terms of higher-order dispersion. Due to this dispersion mis-match, the compressor could not compress the amplified pulse without causing significant wings on the pulse. A matched stretcher-compressor pair was desired and I was continuously thinking about it. At that time, a paper by Oscar Martinez gave me a huge inspiration, which happened when I was skiing with my wife Marcelle. On the chairlift, I thought carefully about Oscar Martinez's paper: he proposed a pulse compressor that combines a grating pair and a telescope of magnification unity. Unlike the Treacy compressor that always provides negative dispersion, this Martinez compressor can operate in either negative or positive dispersion region. I suddenly realized that the Martinez compressor in the positive dispersion region was a perfectly matched stretcher for the Treacy compressor. I ended the skiing immediately, went back to the lab, and asked my students to experimentally confirm it. Later, they showed that the Martinez stretcher could stretch an 80-fs pulse by 1000 times and subsequently the Treacy compressor could recompress it by the same factor. This stretcher-compressor has become a standard arrangement in current CPA systems.

Guoqing Chang: How did you realize that CPA could enable generation of laser pulse with Petawatt peak power?

Gérard Mourou: In the Laboratory for Laser Energetics at the University of Rochester, we have a laser system with kilojoule pulse energy. In fact, if I compress the pulses to picoseconds, I can get Petawatt peak pulse lasers. So, it’s a natural thing to do.

Guoqing Chang: Have you thought of filing a patent for CPA?

Gérard Mourou: Yes, I did think about patenting CPA technology at first. However, when I was at the University of Rochester, I consulted a patent attorney, and he didn't believe in the importance of CPA. Since I was only a young scientist, I did not continue to push forward with it. Later, I moved to the University of Michigan, and it became more difficult for me to patent my work at the University of Rochester.

Guoqing Chang: In 1988, you moved to the University of Michigan, and established in 1990 the Center for Ultrafast Optical Science (CUOS)—a Science and Technology Center sponsored by the National Science Foundation. One mission of CUOS was to "bring big science to lab". What does it mean?

Gérard Mourou: Well, 'big science' here refers to large particle accelerators. In fact, CPA technology can be used to compact the particle accelerators, and we can use high power laser pulses to obtain powerful acceleration fields, which are 1,000 times more efficient than traditional particle accelerators. If this plan is realized, it will be possible to move large scientific devices into laboratories and help people explore more secrets of nature.

Guoqing Chang: In 1994 at CUOS, your group discovered the nonlinear phenomenon called filamentation, which found many important applications. How did you discover it?

Gérard Mourou: Laser pulse filamentation is a complex nonlinear optical phenomenon in which high-power laser pulses ionize air by self-focusing of powerful pulses, which is discovered by chance in experiments.

At that time, we wanted to use ultrashort laser pulses for radar ranging, and because laser pulses are short, we can accurately measure a millimeter range over a kilometer distance. In this application, laser pulses need to travel long distances in the atmosphere, so we have to consider the nonlinear effects of laser pulses traveling through the air.

There are two ways of applying pulse lasers into ranging: one is to emit short pulses; and the other is to transmit a stretched pulse and then compress the echo signal. For long-distance ranging situations, we believe that the second option is more advantageous, because you cannot inject enough energy into a short pulse to guarantee the intensity of the echo signal. Later, we conducted experiments comparing the advantages and disadvantages of these two methods. My colleagues and I shot stretched and short pulses at the target and found that whenever the short pulses hit the target, we could always observe a spark, and we know that this spark should be generated by the interaction between the pulse and the target. So, we discovered the phenomenon of 'filamentation' by chance through this experiment.

Guoqing Chang: Nowadays, millions of people had laser eye surgery—a procedure that involves using femtosecond pulses. The technology originated from an accident in your lab at CUOS. Can you tell us more about the birth of this technology?

Gérard Mourou: This story took place thirty years ago when I tested damage threshold of laser pulses on materials at the University of Michigan. During the experiment, one of my graduate students, Detao Du, unconsciously removed his goggles because the laser goggles blocked part of the operational field of view, and femtosecond laser pulses entered his eyes. However, when he was taken to the hospital, Ron Kurtz, the ophthalmologist on duty, observed a "perfect" circular injury to his retina, a feat not possible with other lasers in clinical use at the time. We immediately realized that our pulsed laser could lead to breakthrough applications in the medical field.

Guoqing Chang: In 2005, you returned to France and initiated the Extreme Light Infrastructure (ELI). What motivated you to propose ELI?

Gérard Mourou: When I returned to Europe, European governments were looking for scientists to lead the construction of large scientific infrastructures such as particle accelerators and synchrotron radiation sources. Based on my early research in the field of laser fusion at the University of Rochester, I proposed that a laser system with ultra-high brightness and ultra-high intensity could be built, and this idea was supported by the authorities. Based on this idea, I initiated the construction of the Extreme Light Infrastructure (ELI).

Guoqing Chang: In a TEDx talk, you advocated nuclear fission to produce clean energy. What is the critical role that high peak-power lasers play in this area?

Gérard Mourou: Some products of nuclear fission are extremely radioactive and have long half-lives. For example, plutonium-239 has a half-life of about 24,000 years. Theoretically, high-energy laser pulses can accelerate the fission of these radioactive nuclear wastes, greatly shortening their half-lives, and transform nuclear wastes into safe and non-radioactive substances.

On top of that, a CPA-boosted laser could be used to generate fission, providing an alternative to the neutron bombardment method used in current reactors. Thorium is a heavy element found in far greater quantities than uranium; In theory, it could replace uranium in nuclear power production. The by-products of thorium fission are also less harmful than uranium, have a shorter half-life, do not produce plutonium from fission, and have no risk of producing nuclear weapons. But thorium fission is difficult, involving an extra step as compared to uranium fission. The thorium must first be brought to a subcritical level; neutrons from an external source are then used to provoke fission. Energetic ultrafast lasers could play a key role in this process prior to fission, in particular because they allow for a high level of control.

Guoqing Chang: In 2005, Science magazine published 125 important questions. One of them is what is the most powerful laser researchers can build. After 18 years, what is your answer to this question?

Gérard Mourou: I think the key to getting laser pulses with higher peak power is to find new ways of compressing high-energy laser pulses to shorter durations. In recent years, I have been pushing a new technology: thin film compression (TFC). I hope this technology is able to push the laser peak power to the Exawatt (1000 Petawatts) level.

Guoqing Chang: Could you share some wisdoms to the researchers at their early career?

Gérard Mourou: I think it's very simple. If you want to succeed, you must have a real passion and drive for what you do. Charles Townes, one of the inventors of the laser, also said, "Love what you are doing." Try to pick a career that you love, and you will be sure to succeed!

Guoqing Chang: We are celebrating the 10th anniversary of *High Power Laser Science and Engineering*. You published two papers in this journal. Can you say a few words for this journal?

Gérard Mourou: Happy 10th anniversary! ***High Power Laser Science and Engineering*** is a very important and very needed journal in the dynamic field of high power lasers. There are a wide range of applications both in science and in engineering. It is very exciting to be in this field. There is still a lot of room for development, and many new things are waiting for people to explore and complete. If you are looking for some research topics, devoting yourselves to the field of high-power lasers is a worthwhile choice.