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Around the genesis of femto-lasers

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The laser was born from a strong competition between large industry labs and the academic world. Guess who won.
6 months later Ali Javan produced the first Helium-Neon laser at Bell labs, Murray Hill, N-J
Diving towards short durations 1

- **Mode-locking ps**
- **Q-Switch ns**
- **Spikes μs**
- **flash ms**

Duration in fs decades

- 1960
- 1970
- 1980
- 1990
Controlling passive mode-locking

Then came a decade of exploration of active and passive mode-locking

Passive mode-locking based on dye lasers

Playing with the relative position of the gain and the saturation it was observed that the collision of the pulses inside the saturable absorber efficiently generated short sub-picosecond light pulses

Sub-picosecond pulses but highly unstable

Here comes the colliding pulse mode-locked

Charles Vanel Shank

CPM ~ 1980

Automatic synchronization

60 fs

The action was taking place in the Holmdel Bell Labs facility in New-jersey.

The Main building was shaped as an integrated circuit chip.

The water tower was shaped as the original transistor developed by Bell.
Diving towards short durations 2

- Flash ms
- Spikes µs
- Q-Switch ns
- Mode-locking ps
- CPM
It is worth noting, here, that the full project in Shank's group was to set up a full instrument and the tools necessary for performing real experiments.

- oscillator
- amplifier
- pulse compressor
- white light generator
- auto & cross correlator
Four stages amplifier

70 fs pulses, 0.3 GW/pulse @ 10 Hz
Taking care of the group velocity dispersion

A grating compressor allows for the rephasing of a pulse frequencies that have been dispersed when crossing a transparent material with positive index of refraction.

Time to do experiments

It takes only 300 fs for Silicon to melt under irradiation @ 620 nm


First CPM ever

Right -> left

Charles V. Shank
Richard L. Fork
Fred Beisser
Charles IV Hirlimann
Richard Yen
This paper lead to intracavity compression

Fig. 2. Cavity configuration. The argon-laser pump mirror has a radius of curvature of 3 cm. The focusing mirrors around the amplifying and absorbing jets are, respectively, M1 and M2 (= 6 cm) and M4 and M5 (= 3 cm). The cavity mirror M3 has a radius of curvature of 1 m. The perimeter of the resonator is 3.6 m.
In 1982, Jean-Claude Diels, @ North Texas U. recognized the negative dispersion occurring inside the cavity of the CPM. He cured this chirp by adding a prism inside the cavity.

In 1984, Oscar Martinez from the Argentinian Scientific and Technical Research Council demonstrated the validity of a prisms compressor. More he showed that the Taylor’s 3\textsuperscript{rd} order compensates the 3\textsuperscript{rd} order for gratings.

As Brewster prisms do not loss, the search for a prism compressor was highly desirable for introduction into a laser cavity.

It was not clear though if the shorter pass in air of the red component could compensate for the dispersion in glass.

Generation of optical pulses as short as 27 femtoseconds directly from a laser balancing self-phase modulation, group-velocity dispersion, saturable absorption, and saturable gain

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compressed-CPM ~ 1984

30 fs

Jim Gordon, pope of the soliton propagation in optical fiber, recognized the quasi-soliton behaviour of the CPM*

Much higher stability
Diving towards short durations 3

- Flash ms
- Spikes μs
- Q-Switch ns
- Mode-locking ps
- CPM
- CPM*
In 1986, François Salin @ Institut d’Optique Orsay, using a stroboscopic technique for measuring the autocorrelation of the pulses, demonstrated the quasi soliton behaviour of the compressed CPM.

This work paved the way to understanding the Ti:Sap laser

The key point in this work is the understanding that the very origin of the passive mode-locking in the laser was not the saturation of the absorber but the self-phase modulation taking place in the solvent of the jet!

Self-phase modulation is the key-stone

Then came the “magic” mode-locking

In 1990, Wilson Sibbett @ St Andrew U., Scotland, was exploring broadband gain solid materials looking to getting rid of all these dirty dies. Exploring aluminium oxide crystals doped with titanium, he replaced the gain jet of his commercial picosecond laser with one of these. He then observed that the laser would “magically” run femtosecond when slightly hit.

It was latter recognized that the necessary self-phase modulation was taking place inside the gain crystal.

A low maintenance universal femto laser
60-fsec pulse generation from a self-mode-locked Ti:sapphire laser

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Time for something really new!

Fig. 1. Schematic of the cavity configuration for self-mode-locked Ti:Al$_2$O$_3$ laser. The inset shows the intracavity prism sequence for dispersion compensation.
In 1987, Carlos Henrique de Brito Cruz, from UNICAMP, Brazil, visiting Shank’s Group, did set-up a white light generator based on intense self-phase modulation inside a short mono-mode silica fibber. Taking advantage of the opposite signs of the 3rd order terms of the Taylor’s development of the group velocity dispersion in gratings and prisms compressor he succeeded generating 6 fs pulses.

Scientific applications

Femtosecond lasers did open the way to the study of the fastest phenomena in which electron are involved, that includes material physics, fundamental chemistry, and fundamental biology.

They also found very many applications, such as, for example, material processing or eyes surgery.

Further developments

- As early as 1985, Dona Strickland and Gérard Mourou demonstrated Chirped Pulse amplification that would lead to the present days Extreme Lasers.
- At the very beginning of the century, the first train of attosecond pulses from high harmonic generation was observed.

But these are other stories

Donna Strickland et Gerard Mourou, « Compression of amplified chirped optical pulses », *Optics Communications*, vol. 55, no 6, octobre 1985, p. 447–449

Observation of a train of attosecond pulses from high harmonic generation by P. M. PP. M. Paul, E. S. Toma, P. Breger, G. Mullot, F. Augé, Ph. Balcou, H. G. Muller, P. Agostini, in Science 292, 1689 (2001)