Institute for Physics and Chemistry of Materials in Strasbourg

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Around the genesis of femto-lasers

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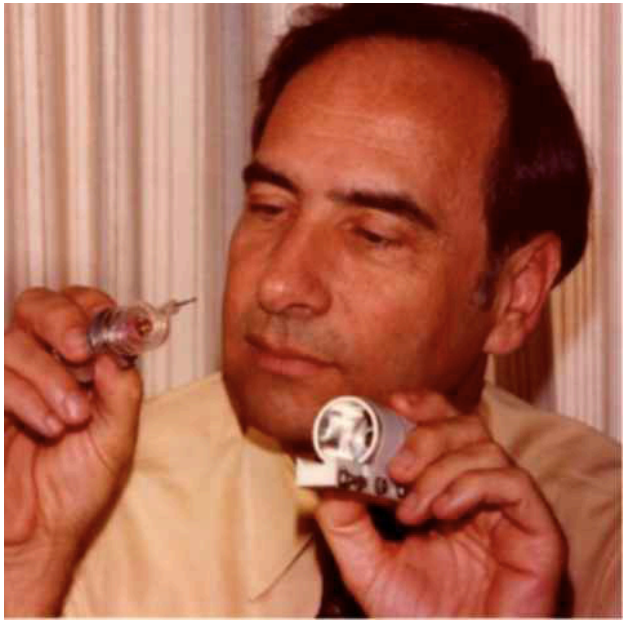
Femto-up 2020 Strasbourg, 8 mars 2021

May 1960
Birth of the LASER

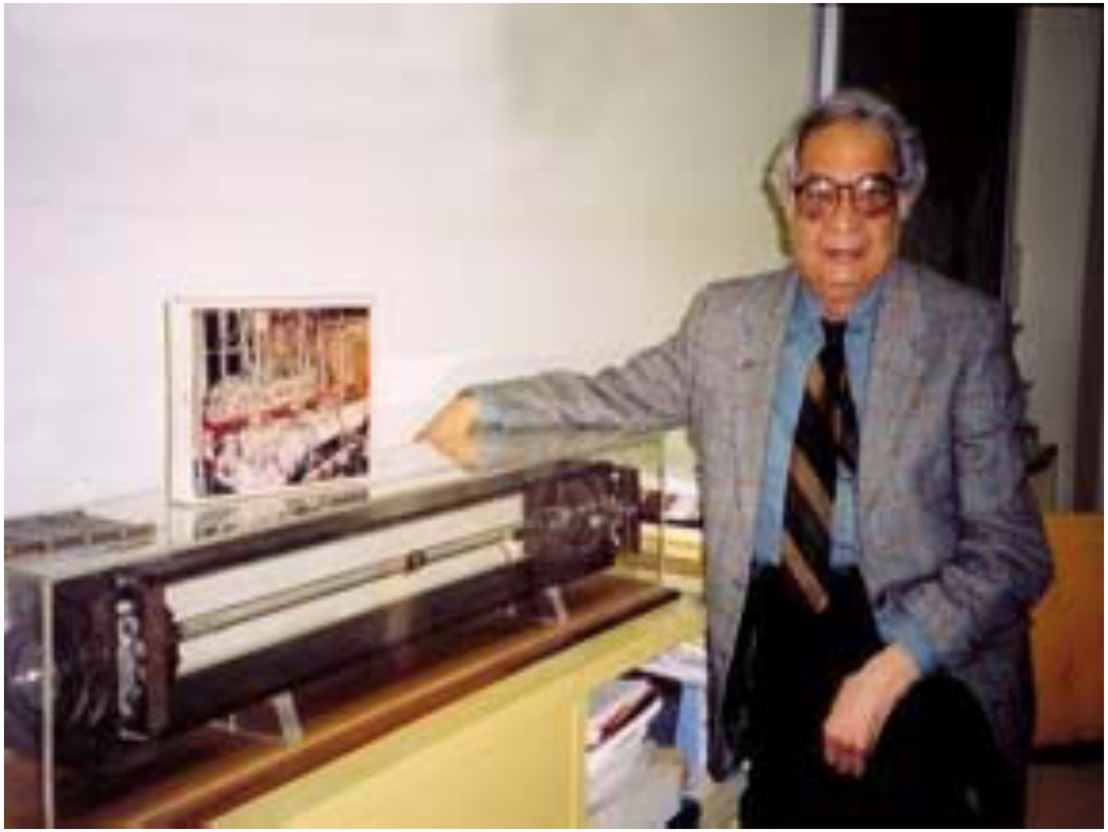
T H Maiman



The laser was born from a strong competition between large industry labs and the academic world. Guess who won.

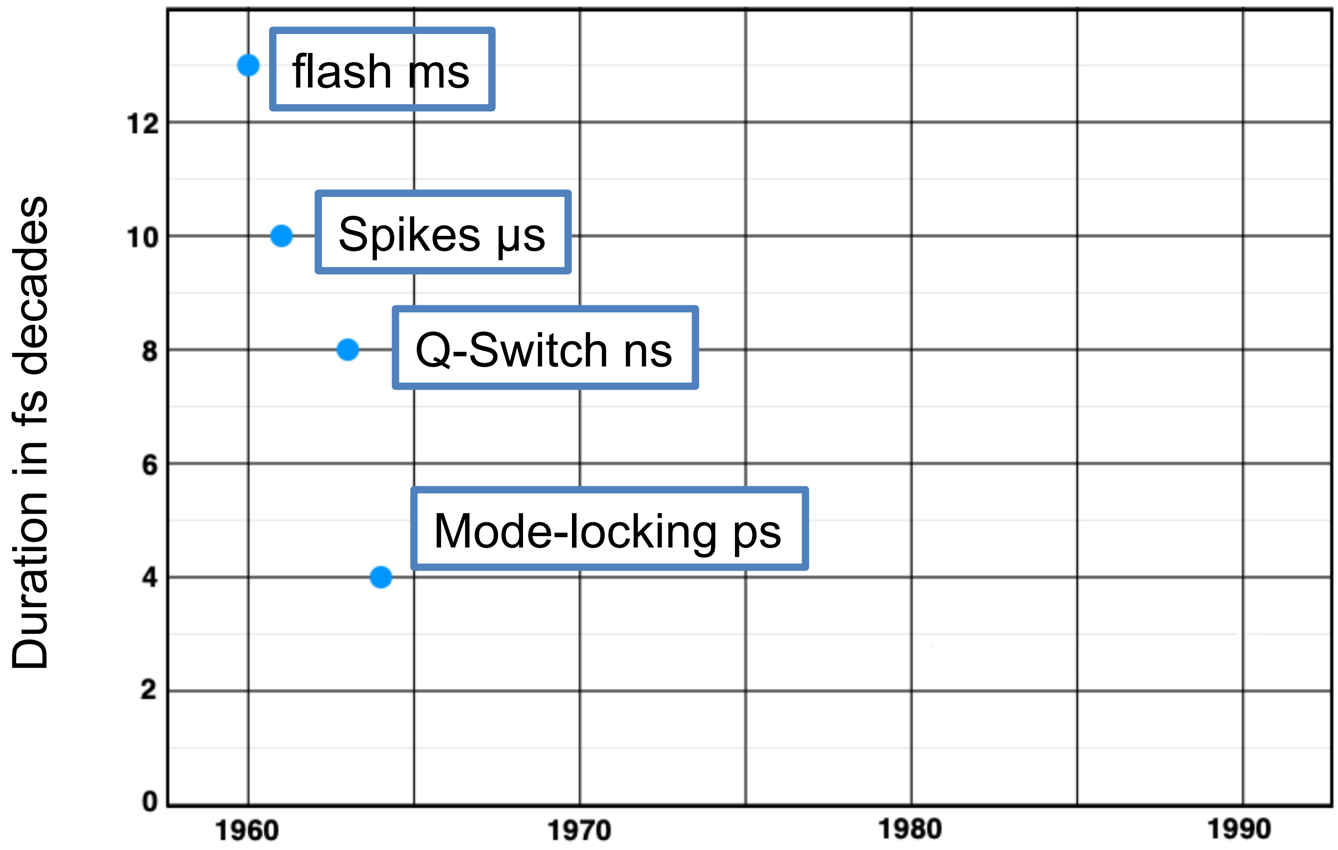
Murray Hill facility

Poor Javan



6 months later Ali Javan produced the first Helium-Neon laser at Bell labs, Murray Hill, N-J

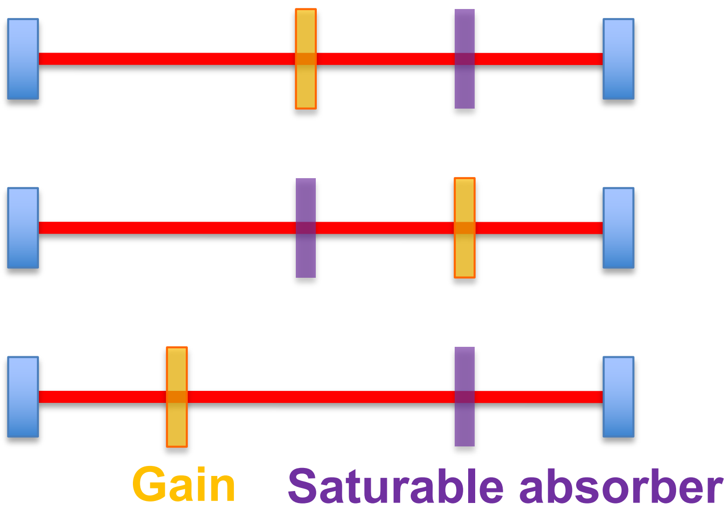
Diving towards short durations 1



Controlling passive mode-locking

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

Passive mode-locking based on dye lasers



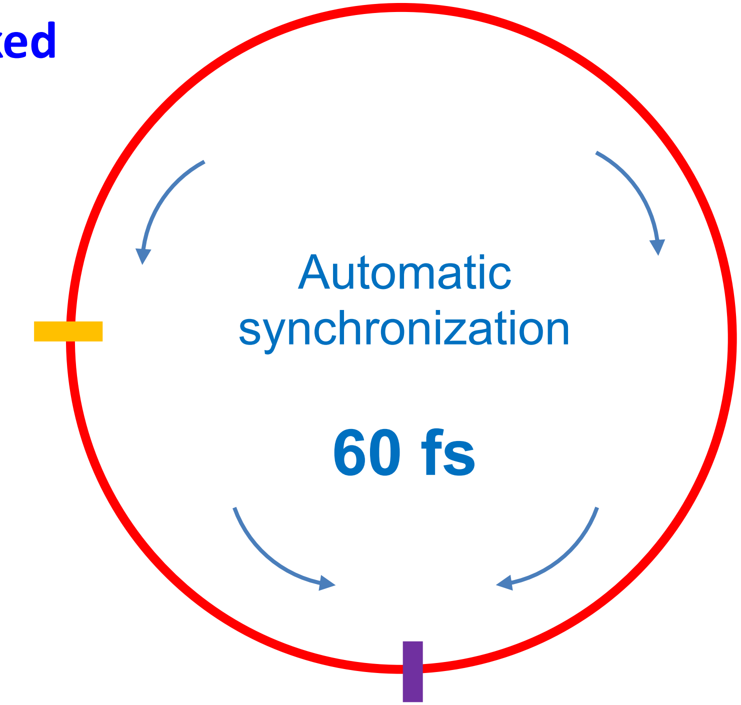
Playing with the relative position of the gain and the saturation it was observed that the collision of the pulses inside the saturable absorber efficiently generated short sub-picosecond light pulses

Sub-picosecond pulses but highly unstable

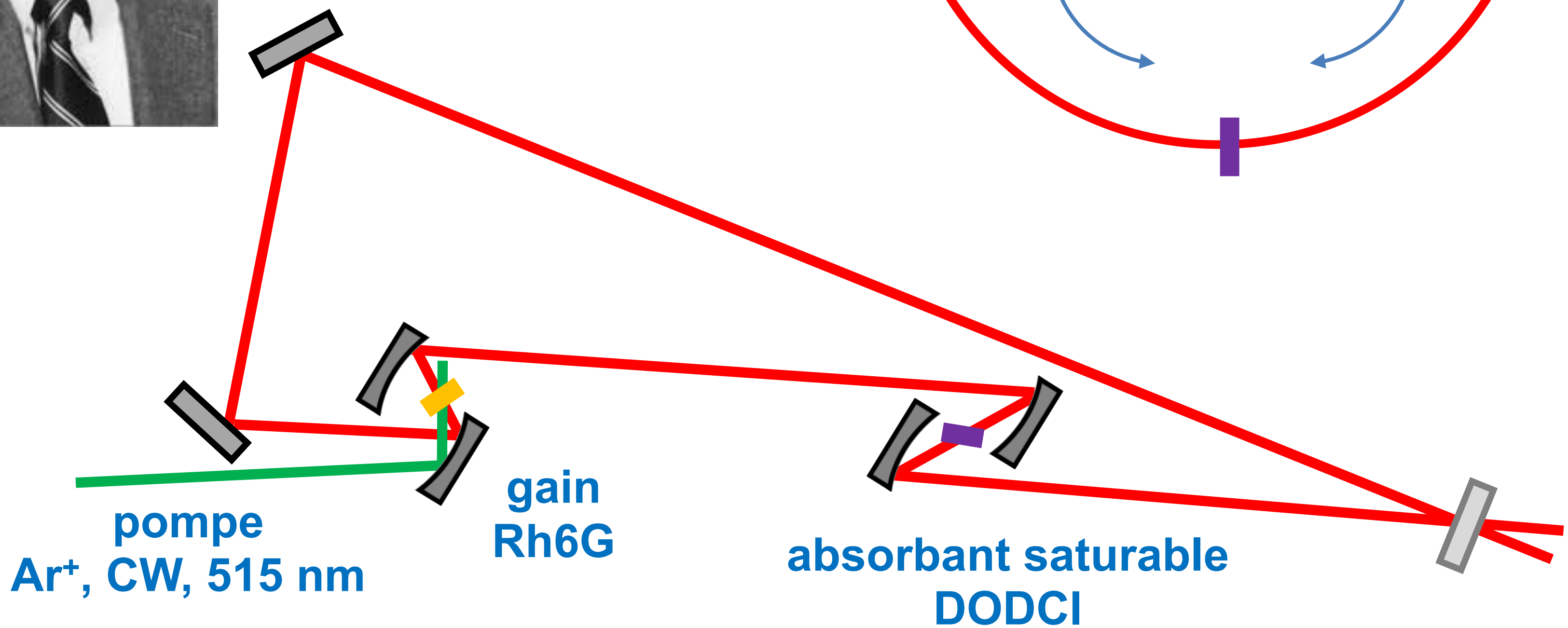
Generation and measurement of 200 femtosecond optical pulses, Diels, J.-C., Van Stryland, E., Benedict, G, Optics Communications, Volume 25, Issue 1, April 1978, Pages 93-96.

Here comes the colliding pulse mode-locked

Charles Vanel Shank



CPM ~ 1980



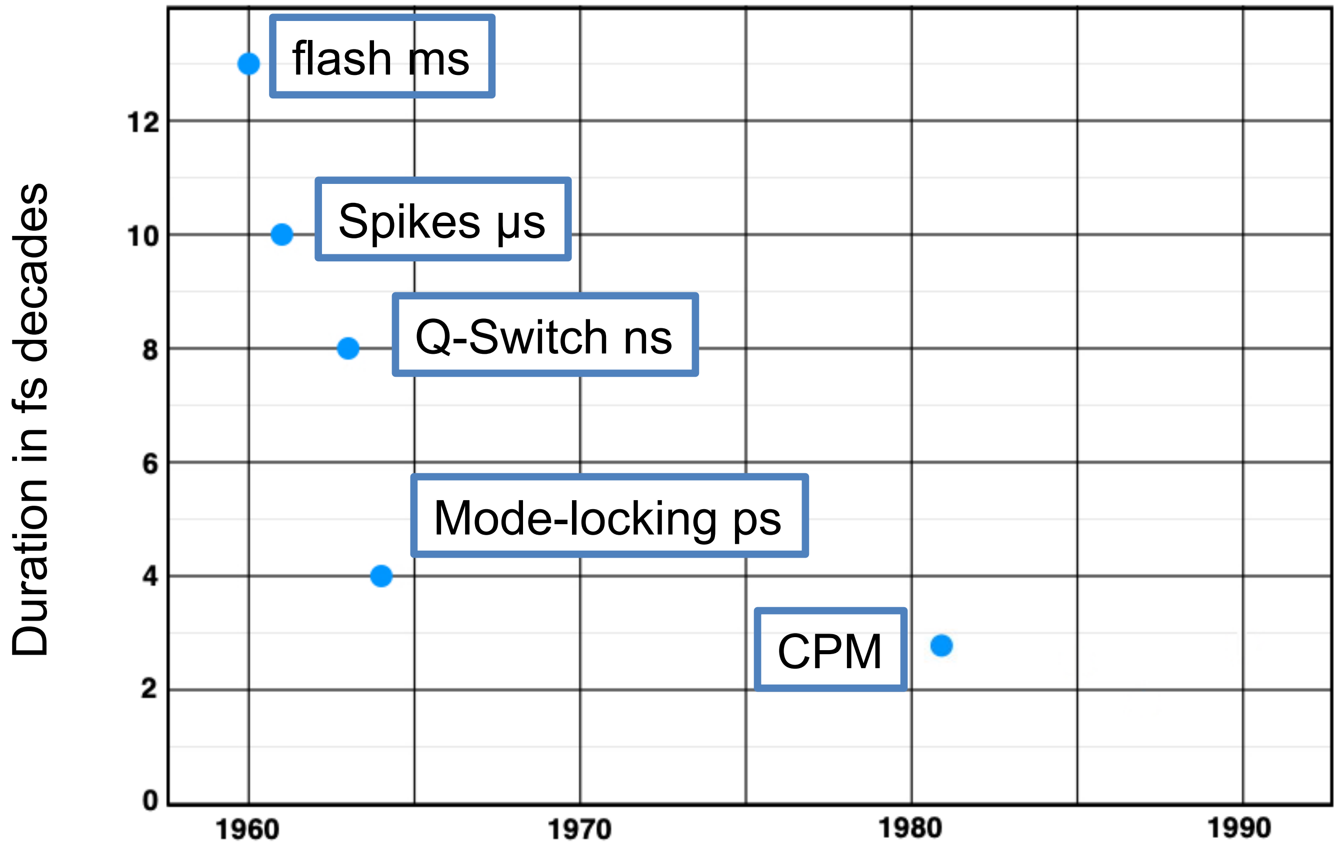
Generation of optical pulses shorter than 0.1 psec by colliding pulse mode locking, by R. L. Fork, B. I. Greene, *and* C. V. Shank, in Appl. Phys. Lett. 38, 671 (1981)

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



500 IEEE JOURNAL OF QUANTUM ELECTRONICS, VOL. QE-19, NO. 4, APRIL 1983

Special Issue Papers

Femtosecond Optical Pulses

R. L. FORK, CHARLES V. SHANK, MEMBER, IEEE, R. YEN, AND C. A. HIRLIMANN

(*Invited Paper*)

Abstract—Recent advances in generation, amplification, compression, and frequency broadening of femtosecond optical pulses are reviewed. We describe use of colliding pulse mode locking to generate pulses of 65 fs duration and pulse compression to reduce those pulse durations to 30 fs. Amplification of femtosecond pulses to gigawatt powers and frequency broadening to obtain white light continuum pulses while retaining femtosecond pulse durations are also examined.

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

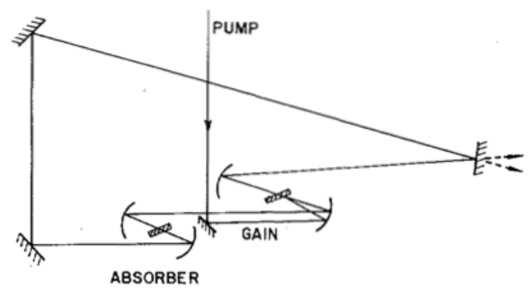


Fig. 1. Colliding pulse mode-locked laser resonator configuration.

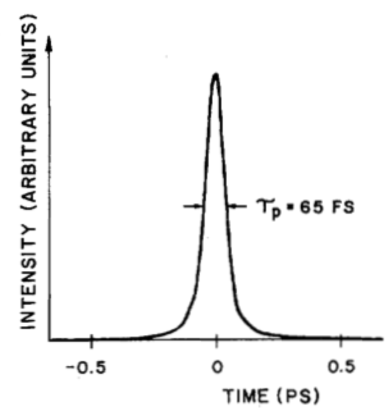
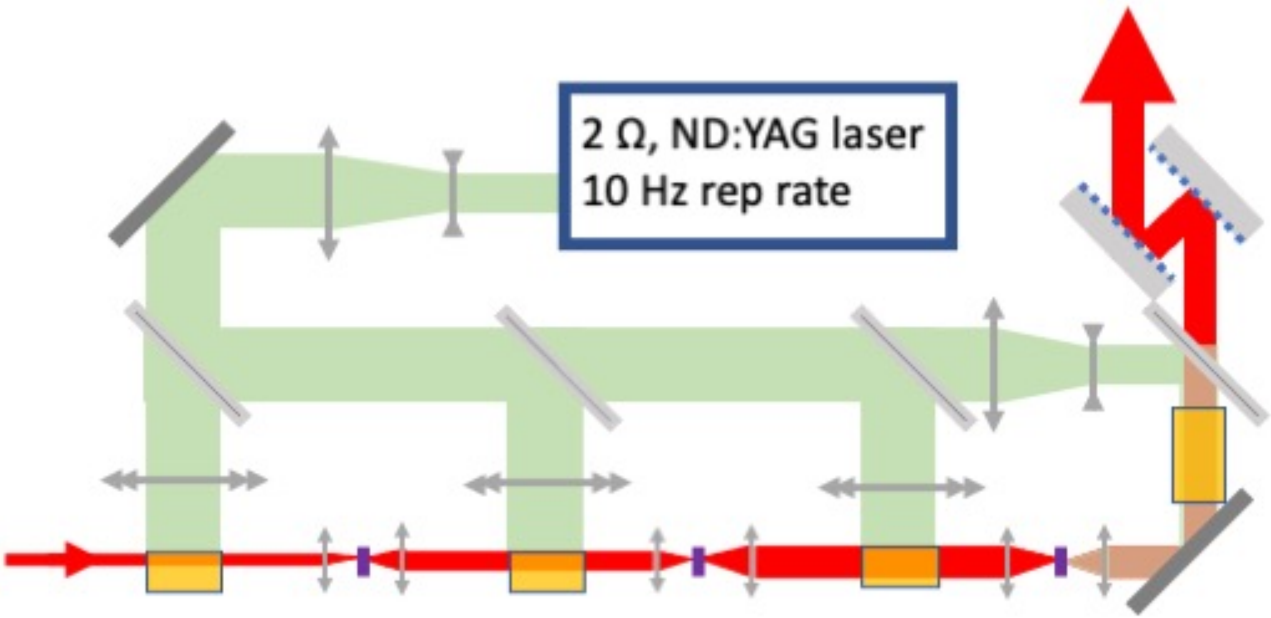


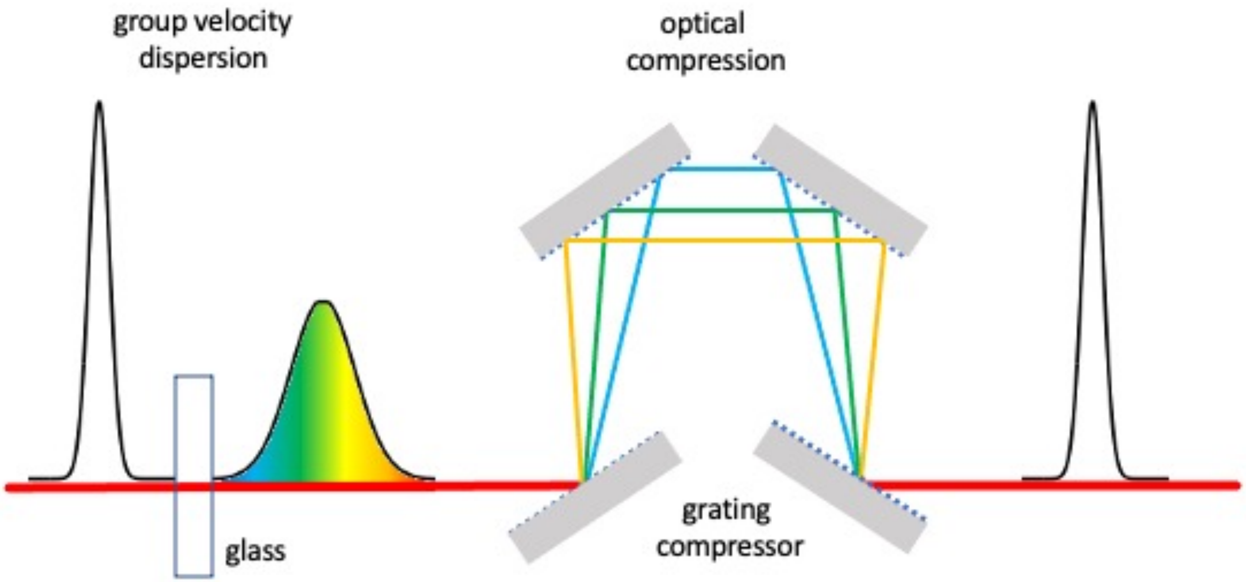
Fig. 2. Autocorrelation function of a pulse from our colliding pulse mode-locked laser. The full width at half maximum corresponds to a pulse duration of 65 fs.

Four stages amplifier



70 fs pulses, 0.3 GW/pulse @ 10 Hz

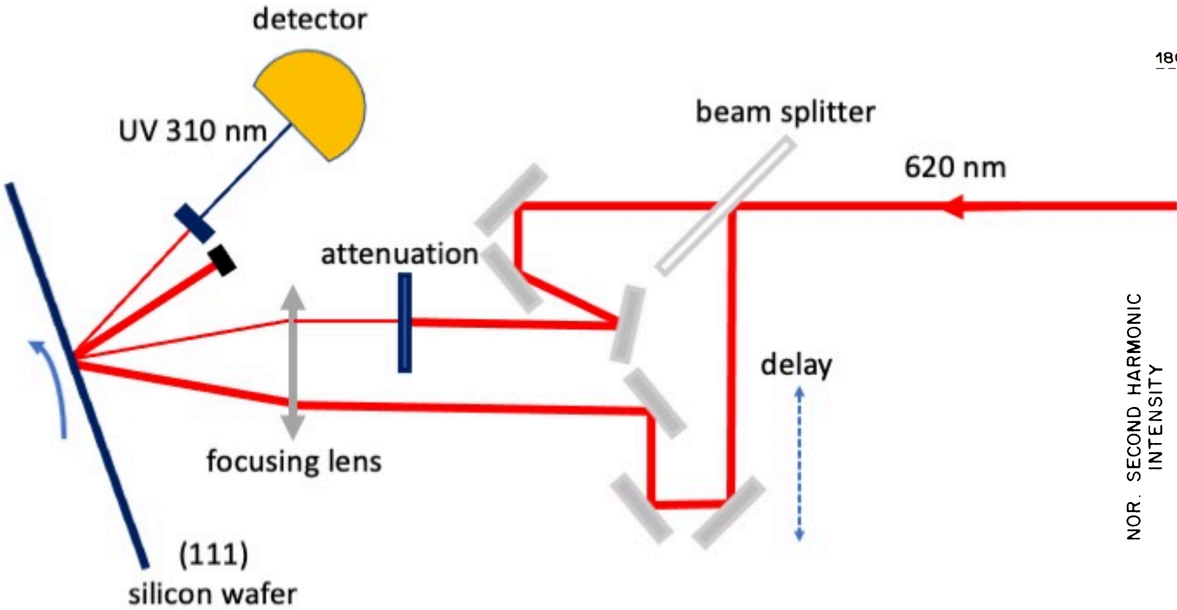
Taking care of the group velocity dispersion

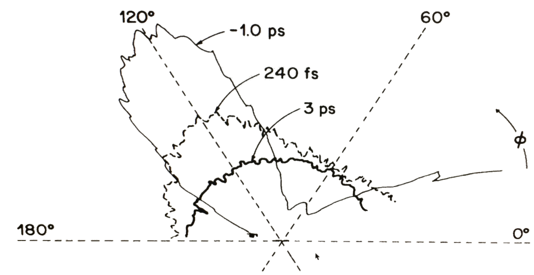


A grating compressor allows for the rephasing of a pulse frequencies that have been dispersed when crossing a transparent material with positive index of refraction.

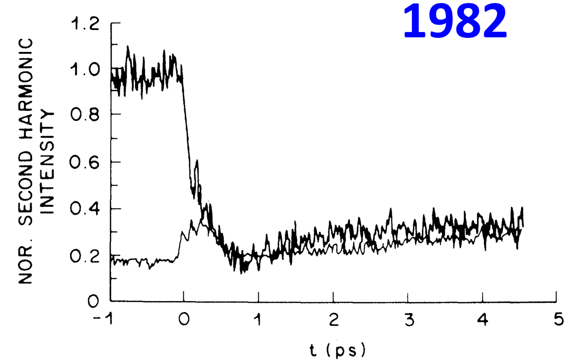
E. B. Treacy, Optical pulse compression with diffraction gratings, IEEE J. Quantum Electron. **5,** 454 (1969).

Time to do experiments





(a)

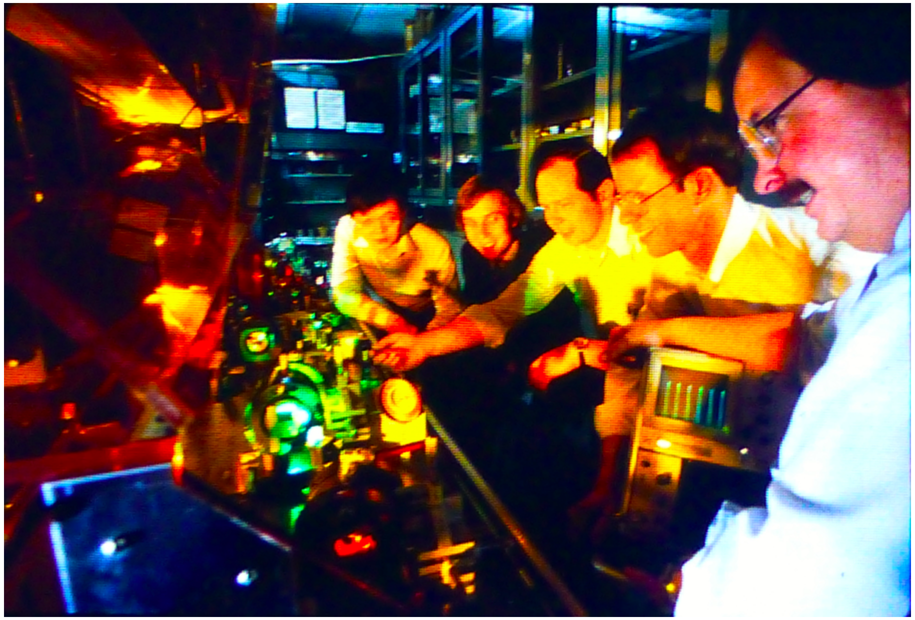


(b)

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

(a) Femtosecond-Time-Resolved Surface Structural Dynamics of Optically Excited Silicon by C. V. Shank, R. Yen, and C. Hirlimann in Phys. Rev. Lett. **51**, 900, 5 September 1983.

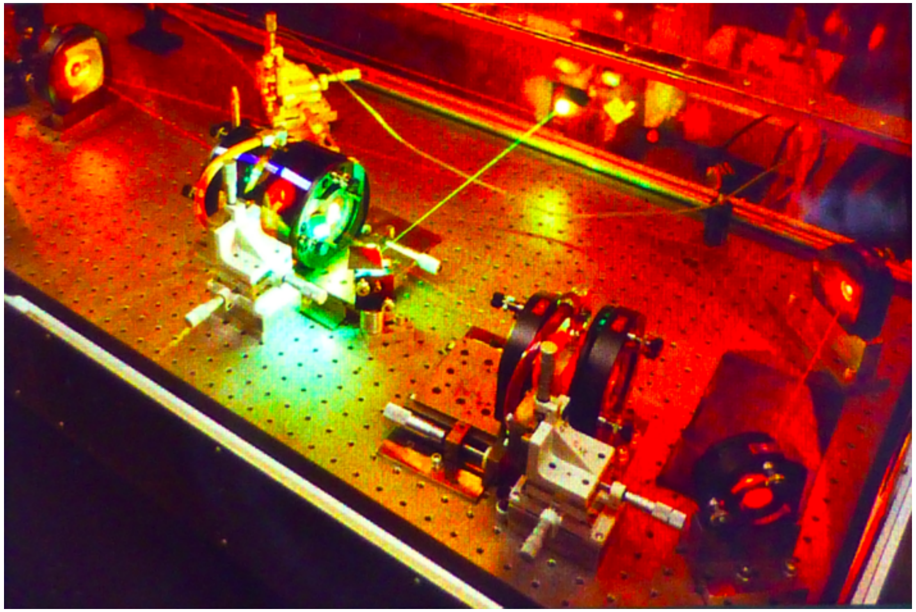
(b) Time-Resolved Reflectivity Measurements of Femtosecond-Optical-Pulse-Induced Phase Transitions in Silicon by C. V. Shank, R. Yen, and C. Hirlimann in Phys. Rev. Lett. **50,** 454, 7 February 1983.



Right -> left

Charles V. Shank
Richard L. Fork
Fred Beisser
Charles IV Hirlimann
Richard Yen

First CPM ever



IEEE JOURNAL OF QUANTUM ELECTRONICS, VOL. QE-19, NO. 10, OCTOBER 1983

Chirp in a Mode-Locked Ring Dye Laser

J. J. FONTAINE, W. DIETEL, AND J.-C. DIELS

This paper lead to intracavity compression

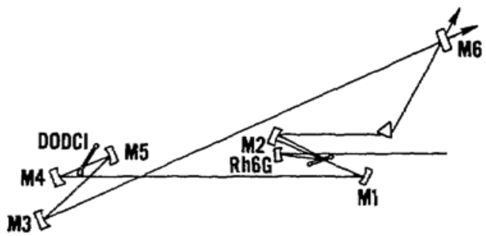
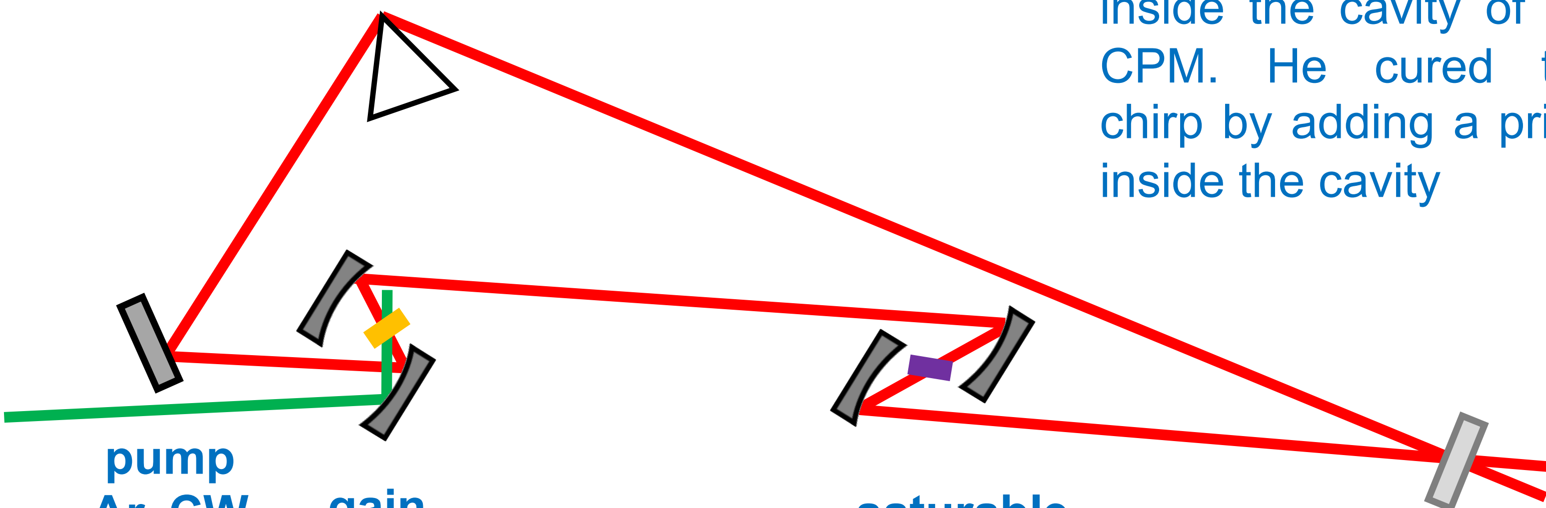


Fig. 2. Cavity configuration. The argon-laser pump mirror has a radius of curvature of 3 cm. The focusing mirrors around the amplifying and absorbing jets are, respectively, M1 and M2 (= 5 cm) and M4 and M5 (= 3 cm). The cavity mirror M3 has a radius of curvature of 1 m. The perimeter of the resonator is 3.6 m.

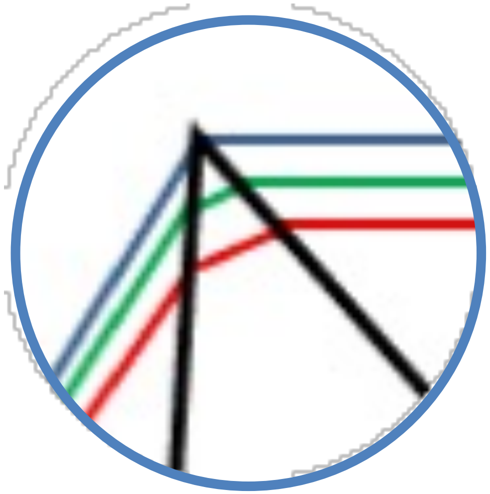
Adjustable GVD inside the cavity

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



going from 90 fs to 60 fs

Intracavity pulse compression with glass: a new method of generating pulses shorter than 60 fsec by W. Dietel, J. J. Fontaine, and J.-C. Diels in Optics Letters **8**, 4, January 1983.

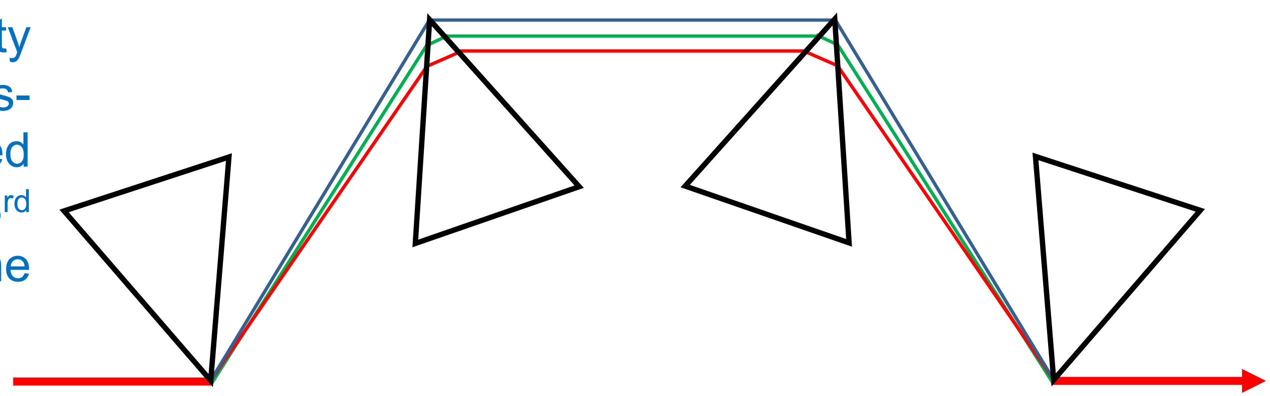


Prisms compressor, 1984

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.

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 3rd order compensates the 3rd order for gratings.



Negative dispersion using pairs of prisms by **O.E.Martinez**, R.L. Fork, and J.P.Gordon, in Opt. Lett. **9**, 156 (1984)

March 1985 / Vol. 10, No. 3 / OPTICS LETTERS 131

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

J. A. Valdmanis

AT&T Bell Laboratories, 600 Mountain Avenue, Murray Hill, New Jersey 07974

R. L. Fork and J. P. Gordon

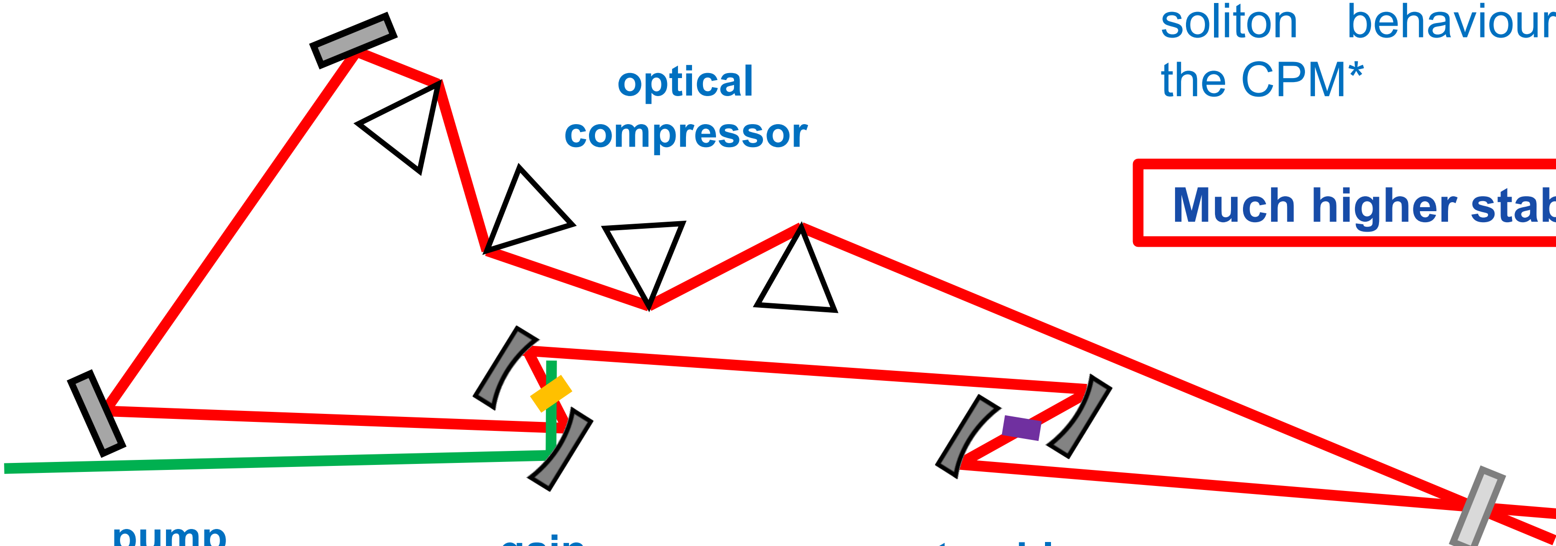
AT&T Bell Laboratories, Crawfords Corner Road, Holmdel, New Jersey 07733

Received November 26, 1984; accepted December 17, 1984

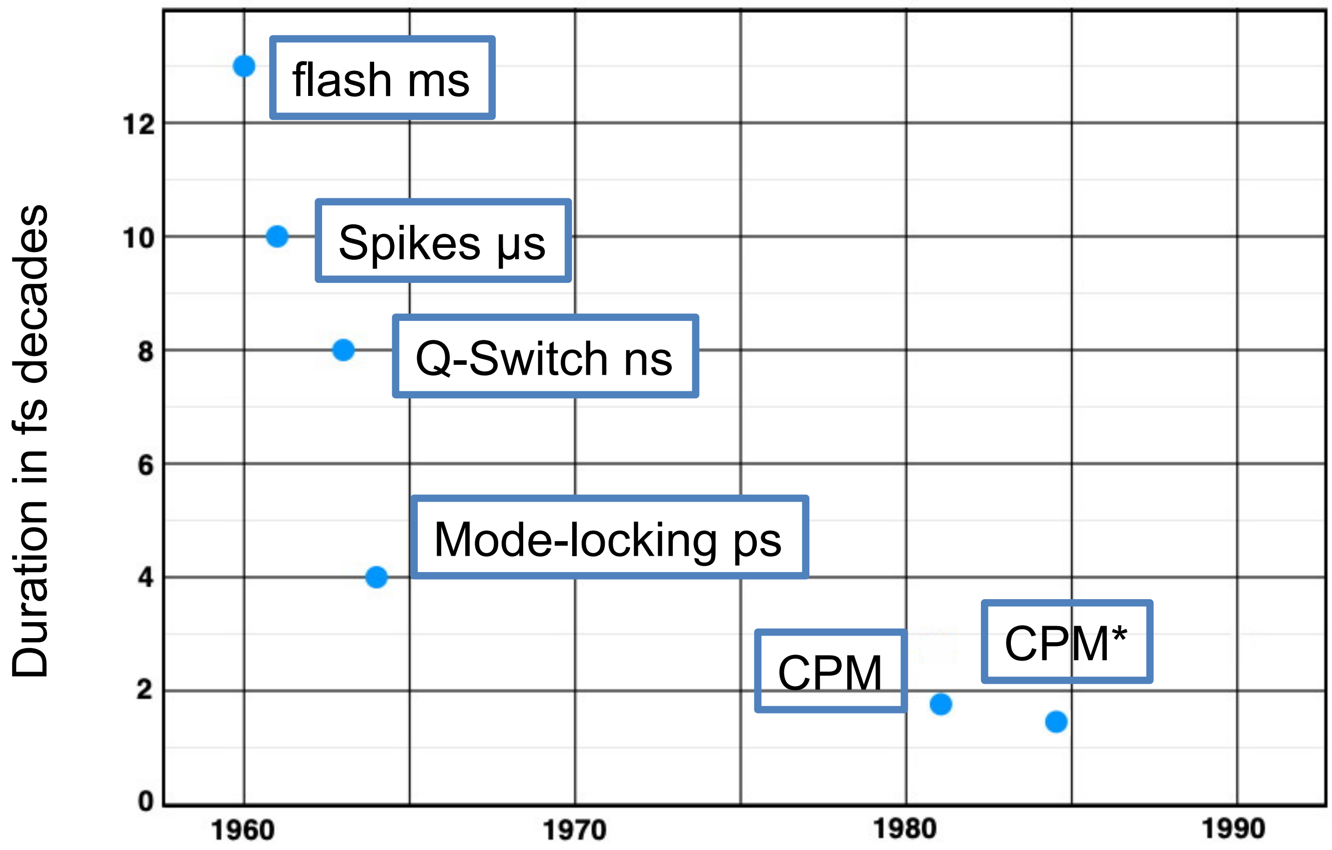
compressed-CPM ~ 1984
30 fs

Jim Gordon, pope of the soliton propgation in optical fibber, reco-gnized the quasi-soliton behaviour of the CPM*

Much higher stability



Diving towards short durations 3



VOLUME 56, NUMBER 11 PHYSICAL REVIEW LETTERS 17 MARCH 1986

Observation of High-Order Solitons Directly Produced by a Femtosecond Ring Laser

F. Salin, P. Grangier, G. Roger, and A. Brun
Institut d'Optique Théorique et Appliquée, Centre Universitaire d'Orsay, 91406 Orsay Cédex, France
(Received 9 January 1986)

In 1986, François Salin @ Institut d'Optique Orsay, using a stroboscopic technique for measuring the auto-correlation of the pulses, demonstrated the quasi soliton beheviour of the compressed CPM.

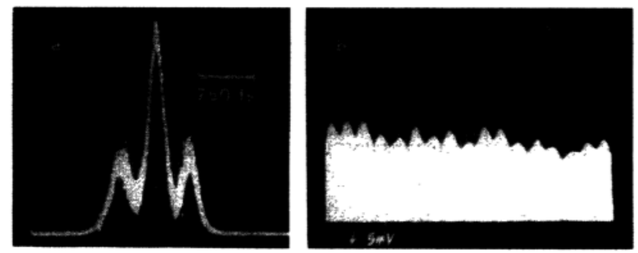


FIG. 1. (a) Autocorrelation trace obtained with an excess of positive GVD; (b) pulse-train envelope under the same experimental conditions.

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

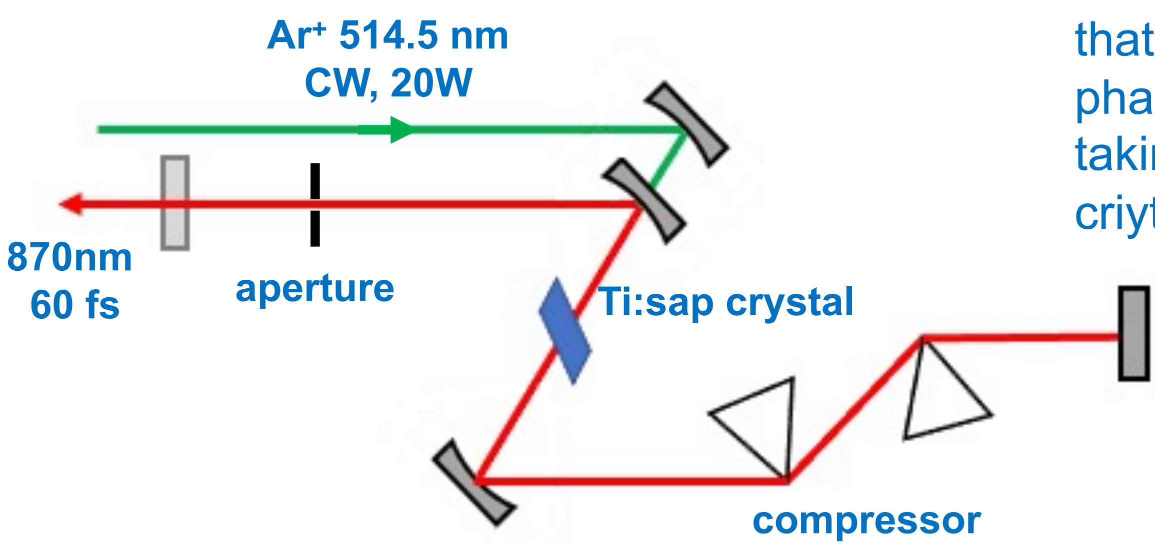
The key point in this work is the understanding that the very origin of the passive mode-locking in the laser was not the saturation of the absorber but the self-phase modulation taking place in the solvent of the jet!

Self-phase modulation is the key-stone

F. Salin, P. Grangier, and A. Brun, Phys. Rev. Let., **56**, 1132 (1986)
D. E. Spence, P. N. Kean, and W. Sibbett, Optics Letters, **16**, 42 (1991)

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 criytal.

A low maintenance universal femto laser

60-fsec pulse generation from a self-mode-locked Ti:sapphire laser

D. E. Spence, P. N. Kean, and W. Sibbett

J. F. Allen Physics Research Laboratories, Department of Physics and Astronomy, University of St. Andrews, North Haugh, St. Andrews, Fife, KY16 9SS, Scotland

Time for something really new!

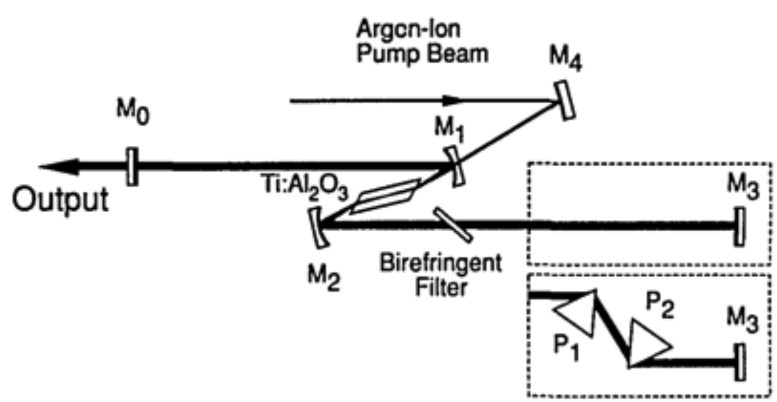
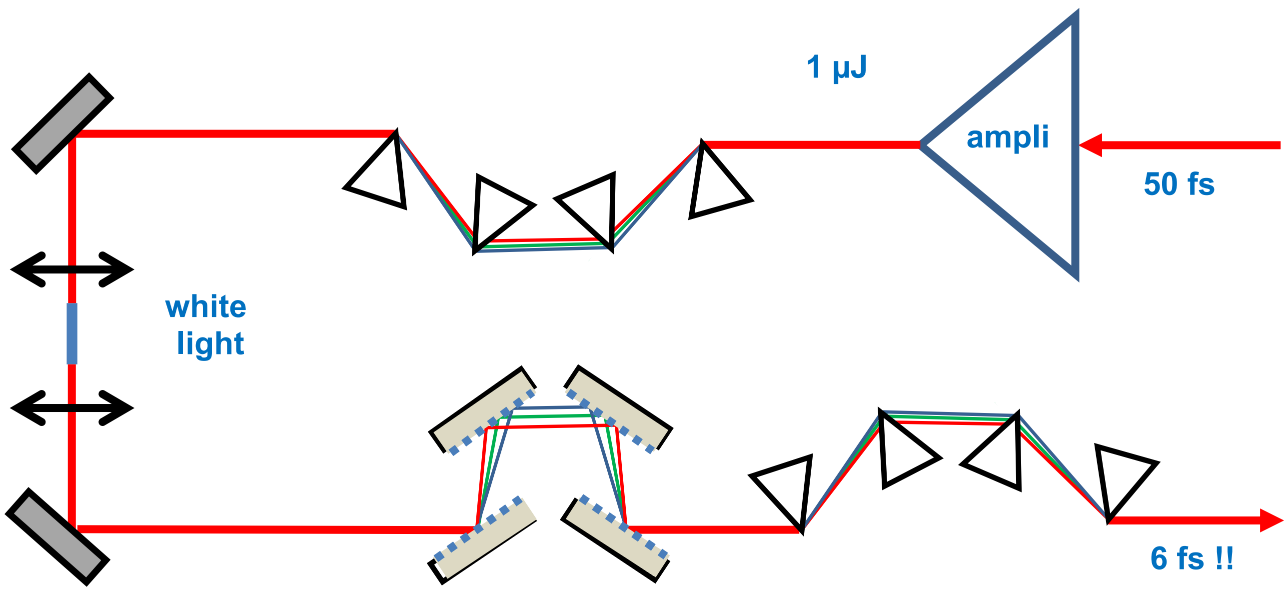


Fig. 1. Schematic of the cavity configuration for self-mode-locked Ti:Al_2O_3 laser. The inset shows the intracavity prism sequence for dispersion compensation.

Femto-up 2020 Strasbourg, 8 mars 2021

Diving deeper! **1987 6fs**

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.



R. L. Fork, C. H. Brito Cruz, P. C. Becker, and C. V. Shank, "Compression of optical pulses to six femtoseconds by using cubic phase compensation," Opt. Lett. **12**, 483-485 (1987)

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)