Observation of the 0-fs pulse

By W.H. Knox, R.S. Knox, J.F. Hoose, and R.N. Zare

The quest for the world's shortest laser pulse has led to a remarkable pace of development in ultrafast laser technology. Although pulses of only a few cycles duration have been made, clearly the observation of a 0-fs pulse would represent a key result in this field (see Fig. 1). In most experiments, a 100-fs pulse is amplified and passed through a nonlinear medium, generally a simple single-mode silica optical fiber. The resulting nonlinear propagation creates a large bandwidth increase, and, with careful control of subsequent optical phases, significant compression ratios have been obtained. A simple linear extrapolation predicted that continued progress should result in an important milestone (dashed line): the pulsewidth should have gone to zero in late 1986 and become negative in 1987. Incorporation of prisms have produced at best 6-fs (three-cycle) pulses.

We show that the reason for this pause in history has been the choice of nonlinear medium. Single-mode fused silica fibers are not capable of generating enough bandwidth to approach the 0-fs limit and beyond with realizable intensities. Our new nonlinear medium consists of a short length (1–10 mm) of zirconium encrusted high-T_c superconductor microcrystallite doped neodymium aluminate fiber maintained near the superconducting transition by a liquid nitrogen cooled cryostat with optical access ports. A strong pulsed magnetic field parallel to the fiber axis is synchronized with the laser, providing 40–80 T peak field strength at 8 kHz repetition rate. We study the pulse evolution as a function of propagation distance and record conventional auto correlations.

Figure 2 shows our results. At 3

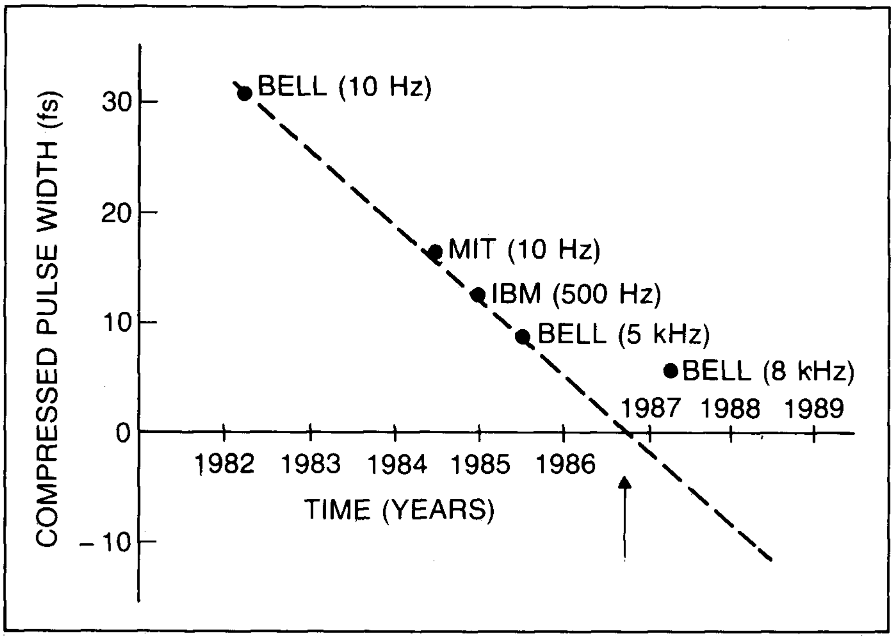

FIGURE 1. Evolution of pulse compression. The dashed line shows that in 1985 the 0-fs pulse was predicted to occur in late 1986. New nonlinear materials now allow us to attain this limit and beyond. Applications of large-negative-pulsewidth optical pulses should be abundant.

W.H. KNOX of AT&T Bell Laboratories, R.S. KNOX of the University of Rochester's Department of Physics and Astronomy, J.F. HOOSE of Milton Roy Inc., and R.N. ZARE of Stanford's Department of Chemistry carried out this work especially for the April issue of *Optics & Photonics News*.

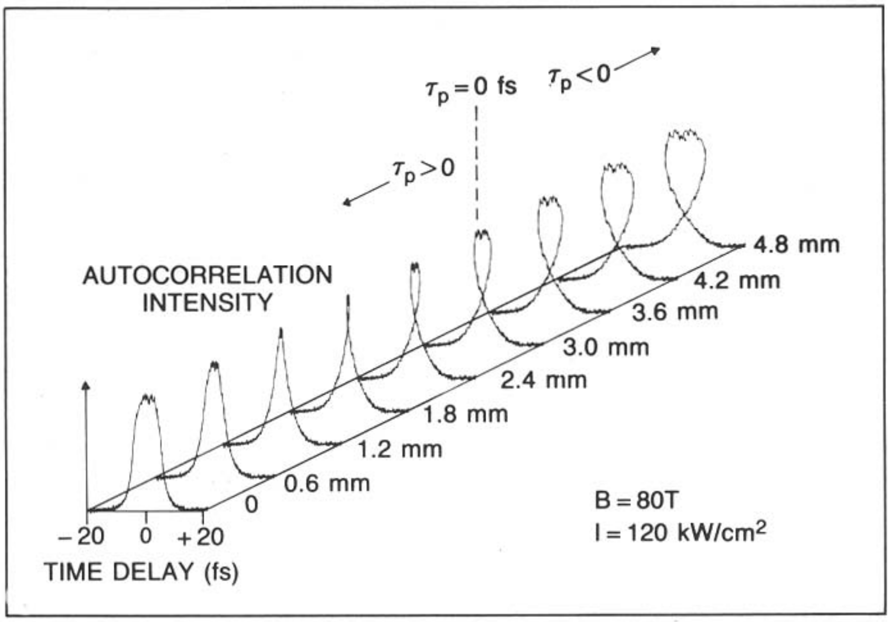

FIGURE 2. Autocorrelations of compressed pulses as a function of fiber length. We clearly observe the transition from normal pulse compression to 0-fs compression and beyond to the negative limit. We cannot test the uncertainty principle because the 0-fs pulse has no energy.

mm, note that the pulse FWHM actually goes to zero, and with longer propagation distance continues to go negative. This results, we believe, from the re-entrant behavior of the effective nonlinearity due to local-field effects in our microcrystallites. It is not clear how the nonlinear response exactly manages to modulate the dielectric function in such a way as to effect essentially a "wormhole" for passage of phase (not amplitude) information between the different parts of the pulse. More theoretical work is needed here.

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We tried to measure the power spectrum for the case closest to the 0-fs pulse. Uncertainty relations might appear to require an infinite bandwidth for a 0-fs pulse. Interestingly, the spectrum of the 0-fs pulse reveals an important feature of the 0-fs pulses that is not true of the 0-pi pulse. A 0-pi pulse has no area, but has energy. A 0-fs pulse has area, but no energy. This can easily be understood—the energy is just equal to the peak power times the pulsewidth. As the width goes to zero, so does the energy. The implications for negative pulsewidths are simply unbelievable.

In conclusion, we have observed the 0-fs pulse for the first time, opening the door to applications of large-negative pulsewidths in computing and communications areas. Implications for a truly universal advanced light source have not escaped our attention. We are investigating possible violations of thermodynamics. Somebody's pulses must be getting longer.