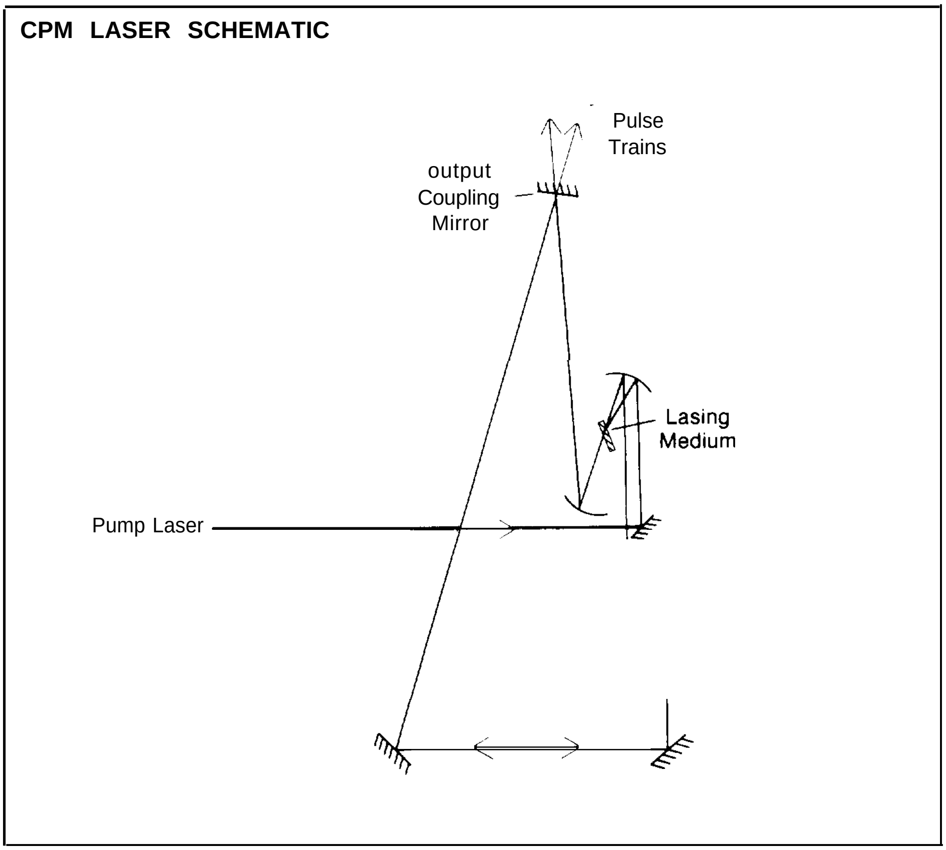
The World's Fastest Laser Oscillator

How short an electrical pulse can be generated by a photoconductor in response to an optical pulse? This question has fundamental significance as well as practical implications. Obtaining the answer requires that the photoconductor be excited by an optical pulse whose duration is short compared to the time scale of carrier decay. Optical pulses of the requisite brevity are produced by a laser first demonstrated in 1981 by R. L. Fork, B. I. Greene, and C. V. Shank of Bell Telephone Laboratories. This so-called CPM (for colliding-pulse mode-locked) laser is illustrated schematically in the accompanying figure, and the accompanying photograph shows the CPM laser built for our research on ultrafast photoconductive circuit elements.

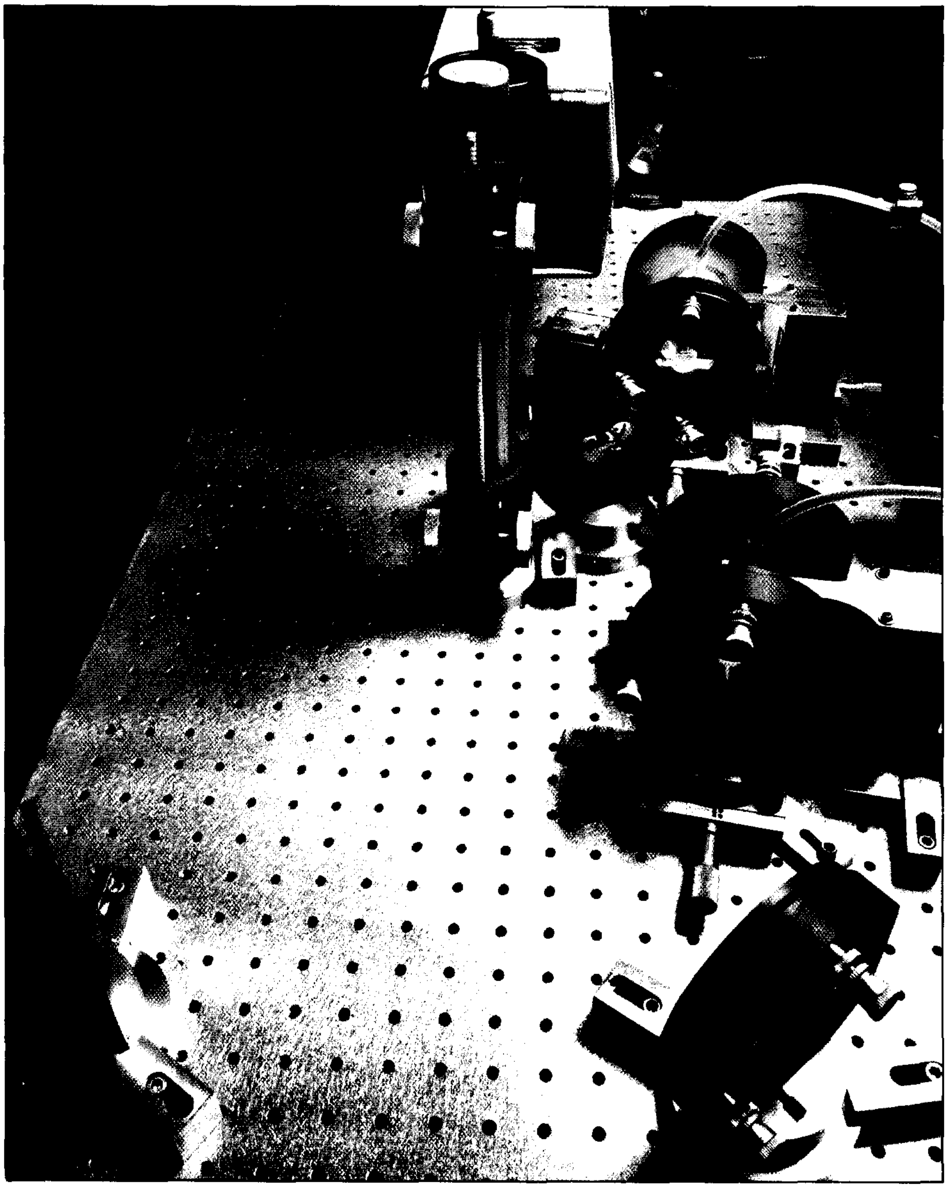
The lasing medium (an organic dye, rhodamine 6-G) is pumped by a continuous-wave argon-ion laser. Pulses of light from the lasing dye travel in both directions through the laser cavity along a roughly triangular path that includes a saturable absorber (another organic dye. 3,3' -diethyloxadicarbocyanine iodide). Interaction of the counterpropagating pulses with the saturable absorber causes a locking in phase of many resonant cavity modes (mode locking), The result is a succession of relatively high-intensity pulses separated by the time required for light to traverse the cavity (about 10 nanoseconds). Two synchronous trains of pulses are extracted from the cavity through the output coupling mirror.

The first CPM laser produced 0.09-picosecond pulses: later versions with prisms in the cavity to compensate for dispersion from the laser mirrors have produced 0.027-picosecond pulses—the shortest available today.



Schematic diagram of a CPM laser. The focusing mirrors for the lasing medium and the saturable absorber have radii of about 10 and 5 centimeters, respectively. The overall cavity length is about 300 centimeters.

A natural question to ask is how the duration of such short pulses can be determined. The standard technique is one known as autocorrelation by second-harmonic generation. A beam of pulses from the laser is split by a beam splitter, one of the resulting beams is fed through a variable optical delay, and both are then focused on a potassium dihydrogen phosphate (KDP) crystal. Nonlinear interaction of two out-of-phase but otherwise identical pulses produces a second harmonic whose maximum amplitude is a



Photograph of the CPM laser built by the Laboratory's Electronic Research and Exploratory Development Group. The lasing medium (yellow) and the saturable absorber (purple) circulate through the tubes at the right, the pump laser is visible at the top, and the output coupling mirror is in the far background.

function of the delay between the two original pulses. Measurement of that amplitude as the delay is varied yields a correlation function (an autocorrelation function, since the two pulses are identical) from which the duration of the pulses is derived. This technique is analogous to that by which the response of an integrated-circuit component is determined from measurements of signal amplitude versus the delay between activation of a photoconductive pulse generator and a photoconductive sampling gate (see main text). ■

continued from page 58

of the circuit to an external sampling instrument. These tasks have in fact proved nearly impossible for signals with frequencies above about 25 gigahertz. (Frequency-domain measurements with a 3-decibel bandwidth of about 25 gigahertz correspond to time-domain measurements with a resolution of about 15 picoseconds.)

Figure 9 shows schematically an experimental setup for investigating a circuit component with the device. Its operation is in many respects similar to that of a sampling oscilloscope. Briefly, a laser pulse induces the biased pulse generator to produce an electrical signal. This signal passes through the component, being modified in the process by its response. The sampling gate, activated by a second laser pulse, feeds the signal during a short interval (the sampling aperture*) to external circuitry that measures its average amplitude during that interval. By varying the relative timing of the two laser pulses. an amplitude versus delay curve known as a correlation function is obtained. Embedded within this correlation function is the response of the component. together with the responses of the pulse generator, the sampling gate, and the interconnections. Extracting the component response requires knowledge or reasonable estimates of the other responses.

The temporal resolution of the device is determined by the sampling aperture, which in turn is determined by the lifetime of carriers in the sampling gate. Thus short carrier lifetime is the key property for the sampling gate, just as it is for the photoconductor radiation detector. In addition, the material composing both photoconductive circuit elements should have high resistivity and high carrier mobility, Furthermore, for greatest utility

---

**The sampling aperture of a photoconductive sampling gate is defined as the, full width at half maximum of the pulse induced in the gate by an ultrashort optical pulse. It is essentially identical to the property defined in detector parlance as response time.*