RADIAL COMPRESSION OF PICOSECOND ELECTRICAL PULSES

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To accelerate electrons to TeV energies, gradients of GV/m are necessary. An alternative to r.f. fields is acceleration by pulsed fields of picosecond duration applied across millimeter gaps.[1] The short pulse prevents breakdown and reduces heating and other losses making possible, at least theoretically, gradients of order 0.5 MV/mm.

At the Laboratory for Laser Energetics (LLE) of the University of Rochester we are investigating the generation of ultrashort (1-10 psec) high voltage pulses by using laser driven semiconductor switches.[2] We are using high resistivity Si (ρ=7kΩcm) and GaAs with Cr-doping as the switch material. The semiconductor is illuminated by amplified pulses from a glass YAG laser system (λ=1.054 μm). Typically the energy is the pulse $E \lesssim 1$ mJ and the pulse duration 1-100 psec depending on the configuration used.[3] Figure 1 shows the electrical pulse generated by a GaAs switch; the overall width is τ = 1 nsec which is typical of the carrier recombination time for GaAs.

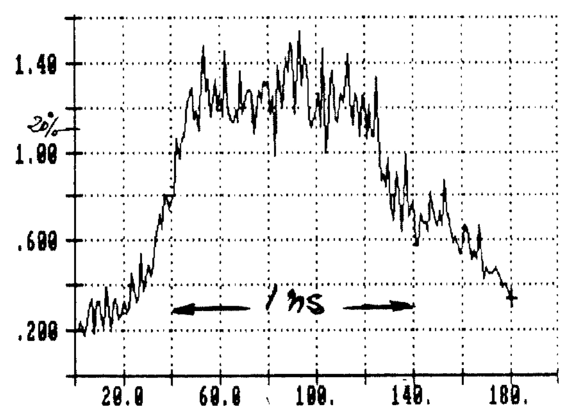

Fig. 1 Pulse generated by switching GaAs.

To preserve the time resolution the electric fields are measured by an electrooptic (EO) sampling technique. A KDP crystal is placed at the location to be sampled and is probed by an optical pulse. The ensuing optical rotation is proportional to the applied electric field and can be detected by standard techniques. By delaying the optical probe it is possible to sample the pulse in the time domain, as indicated by the curve in Fig. 1.

A typical regenerative laser amplifier system is shown in Fig. 2. Short pulses are achieved by compressing the pulse after amplification in a pair of gratings. This is possible because the pulse exiting the amplifier has a frequency chirp imposed on it. At the 1 mJ level we can operate at a repetition frequency of several hundred Hertz. As an example the autocorrelator spectrum of an ultrashort pulse is shown in Fig. 3.

The accelerating structure that we are considering consists of two circular discs and the beam passes through a 1 mm hole at the center. The upper disc is a silicon or GaAs wafer which has been gold coated to provide the second electrode. The disc is illuminated

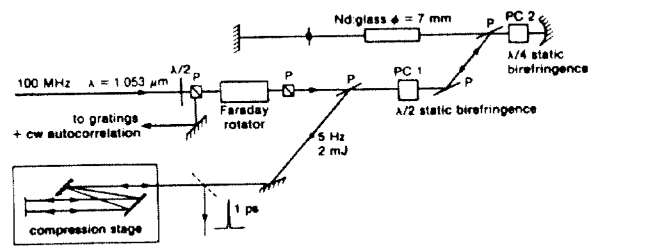

Fig. 2 Light amplification and compression scheme.

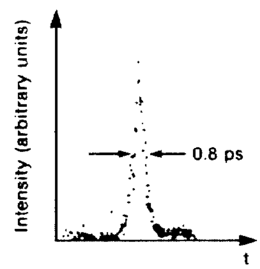

Fig. 3 Single-shot autocorrelation of the compressed, amplified pulse showing a duration of 0.8-ps FWHM.

by a ring focused light pulse which switches the HV onto the inner surface of the semiconductor wafer. This arrangement is shown schematically in Fig. 4. If the voltage at the outer rim of the wafer is V_o, then the expected voltage V_c at the center is

$$V_c = 2V_o \sqrt{\frac{2R}{g+c\tau_R}} \qquad (1)$$

where R is the outer radius, g is the gap between the discs and τ_R the rise time of the pulse.

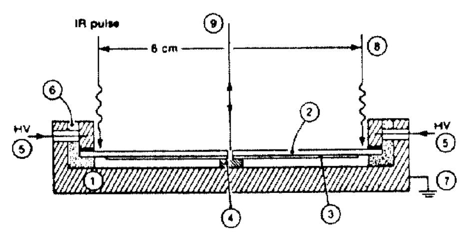

Fig. 4 Cross section of the disc structure: (1) cathode brass disc; (2) silicon wafer; (3) gold coating; (4) KDP crystal; (5) HV feed; (6) insulator; (7) ground; (8) IR pulse; (9) probe pulse.

The results obtained with the prototype structure, which had R = 3 cm and g = 2 mm are shown in Fig. 5. The observed rise time is 24 psec but unfolding the resolution of the 2 mm thick KDP crystal (probed in reflection) yields τ_R = 16 psec. From Eq. (1) the expected voltage is $V_c = 5.9\ V_o$ but we observe a gain of only two. This is attributed to the reflection of the electrical pulse by the KDP ($K_e \simeq 20$) so that only 37% of the field propagates to the center. The theoretical prediction for an optical pulse of 0.1 psec duration (and without the KDP) is shown in Fig. 6.

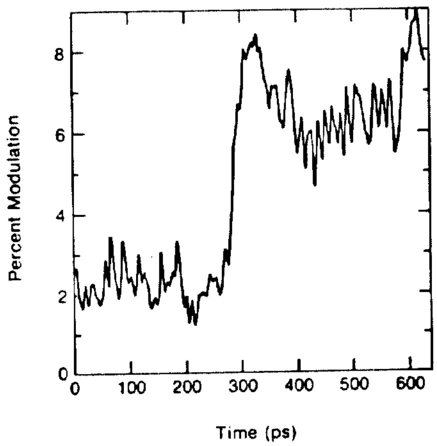

Fig. 5 Measured waveform at center of disc.

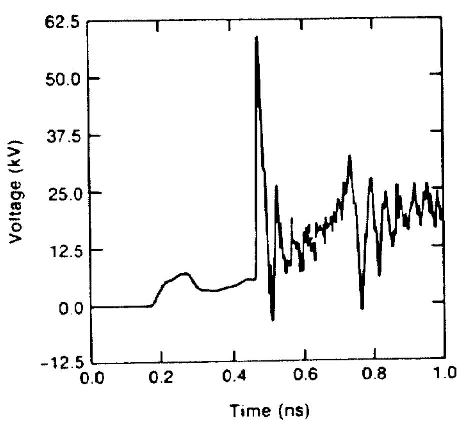

Fig. 6 Calculated waveform at center of disc.

A realistic structure will contain several gaps and in this case the arrangement of Fig. 4 is not adequate but instead the electrical pulse must be injected between the two discs. A possible arrangement which is akin to a Blumlein is shown in Fig. 7 and uses a segmented GaAs ring. Using 500 μm thick GaAs we can hold off 9 kV for over 100 nsec, and can switch with a 90% efficiency. We have not as yet demonstrated gain in this structure. It is also possible to illuminate the wafer along its narrow edge which simplifies the mechanical construction at the cost of more complex optics.

Another problem for a realistic structure is the need to raise the externally applied voltage to $V_o \sim 40$ kV. To accomplish this the prepulse must be shortened to $\Delta t < 10$ nsec by appropriate shaping. We have demonstrated switching of a 20 kV pulse in a coaxial geometry using a 4 mm silicon switch. The resulting pulse is shown in Fig. 8 as monitored at the termination of a matched transmission line. In this case the observed rise time was of order $\tau_R \sim 200$ psec consistent with the width of the laser pulse.

Laser switching of the accelerating field simplifies the problem of synchronizing the source. Electrons will be produced by the same light pulse after quadrupling the YAG frequency into the UV. We will then use the electron beam itself to probe the

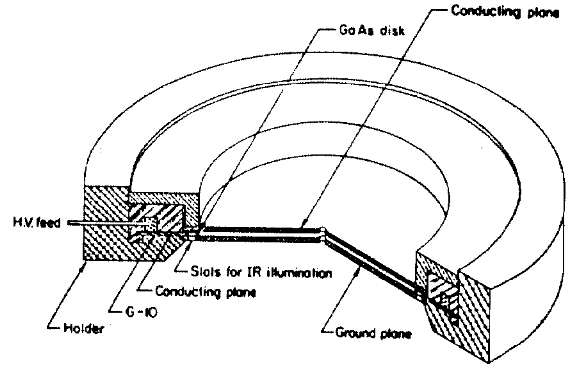

Fig. 7 Blumlein injection.

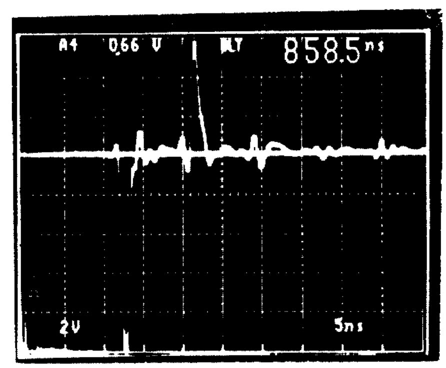

Fig. 8 Switching of 20 kV pulse observed at the end of a 50 ohm transmission lines.

voltage at the center of the structure. This avoids the perturbations introduced by the KDP and can give an indication of expected electron yield. We believe that such a device could yield an electron source with very small emittance.

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References and Notes

(1) W. Willis, CERN internal note EP/WJW/MM-0151D-1984; F. Villa SLAC-PUB-3875 (January 1986).

(2) C. Bamber et al., "Radial Compression of Picosecond Electrical Pulses". To appear in "Particle Accelerators Vol. 22 (1988), gives a more detailed description of the work discussed here.

(3) D. Strickland and G. Mourou, Opt. Communications 55, 447 (1985) and references therein.