ACCELERATION OF PICOSECOND ELECTRON BUNCHES IN A RADIAL TRANSMISSION LINE

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Abstract : A 6cm radius, single stage, electron accelerator that uses a photoconductive switch to couple an electromagnetic pulse into a radial transmission line is being developed. The switch consists of a segmented ring of GaAs which is closed with laser light from a phosphate glass regenerative amplifier. Progress is reported on the acceleration of picosecond electron bunches in fields of the order of several MeV/m.

In response to the demand for charged particle beams with multi-TeV energies, an alternative to conventional radio frequency acceleration using photoconductive switches to couple electromagnetic pulses into a radial waveguide is under development[1]. The acceleration gradient for this new technique has the potential of being 2 orders of magnitude greater than current accelerator technology.

The accelerator structure, shown schematically in figure 1, is a radial waveguide with a Blumlein pulse injection and a photoconductive switch. The ground planes are gold plated brass, the spacer on one side of the injection line is a 1mm thick by 3mm wide G-10 ring, and the switch on the other side of the injection line is a 1/2mm thick by 3mm wide segmented ring of GaAs. The inner conductor of the Blumlein is pulsed with a grounded grid thyratron pulser. The GaAs switch is closed with 5mJ of 1053nm IR in 10ps from a phosphate glass regenerative amplifier. A 1.5kV voltage pulse applied to the switch without and with the IR switching beam is shown in figures 2 and 3 respectively, monitored at the input side of the GaAs switch with an AC high voltage probe.

The first studies performed with this structure were to electro-optically sample the voltage at the center with a

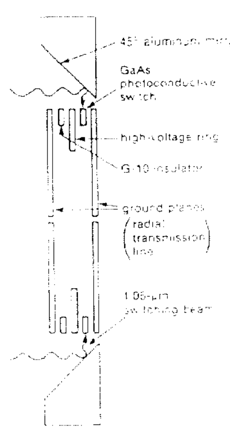

Figure 1: Schematic of the single stage radial accelerator.

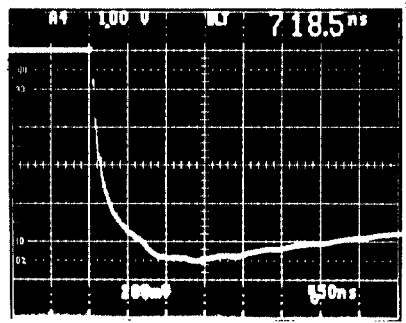

Figure 2: 1.5kV voltage pulse applied to the accelerator without the IR switching beam.

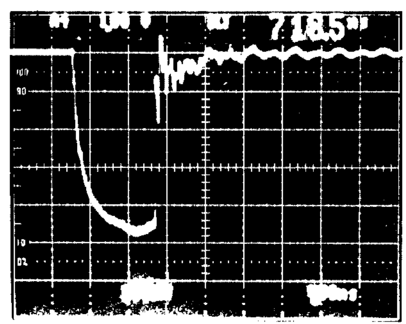

Figure 3: 1.5kV voltage pulse applied to the accelerator with the IR switching beam.

KD*P crystal to determine the time structure of the voltage pulse. About 10% of the initial laser light was converted to 527nm green light for use as a sampling beam. The sampling beam was directed thru a polarizer, thru the center of the accelerator in which was mounted the 10mm square KD*P crystal, thru a second polarizer crossed with respect to the first one, and subsequently into a photodiode. The signal at the photodiode is monitored as the relative path length between the IR switching beam and the green sampling beam is systematically varied. Figure 4 shows a schematic of the set-up for electro-optic sampling, and Figure 5 shows a sampling scan for the structure shown in figure 1 pulsed at 1500 volts.

The spacing between the peaks is not strictly uniform but it is approximately the round trip time for a voltage pulse to travel from the center of the waveguide to the outside edge and back. A radial waveguide has a nonuniform impedence so that if a voltage pulse of magnitude V_0 is injected at the outside edge the voltage at the center will be approximately[2],

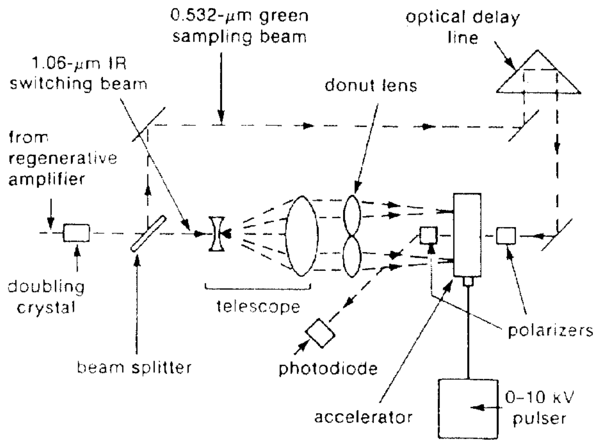

Figure 4: Schematic of electro-optic sampling setup.

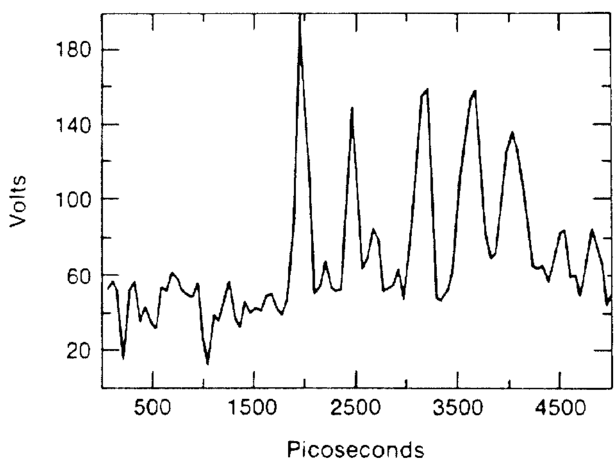

Figure 5: Sampling scan of LINAC structure.

$$V = 2V_0\sqrt{\frac{2R}{g + c\tau}}, \qquad (1)$$

where R is the radius of the waveguide, g is the acceleration gap, and τ is the risetime of the injected voltage pulse. For the 6cm radius structure with a 2mm gap shown in figure 1 and a 10ps risetime pulse, we expect a gain of almost 10. With this particular structure when reflection from the KD*P crystal is taken into account no gain is observed, however our group has observed indications of gain on an earlier prototype accelerator structure[3]. It is difficult to determine the accuracy of the absolute voltage calibration with the electro-optic effect because the calibration is done with DC voltage, and the measurement is performed on a signal with frequency components up to 100Ghz. Also the square sampling crystal we used does not match the round geometry of the radial waveguide, so the voltage measured with electro-optic sampling is only an approximation of what voltage will actually be at the center without the crystal. In addition the presence of the crystal introduces a perturbation in the waveguide structure which introduces additional frequency components and consequently distorts the time structure measured in figure 5, and may in fact account for

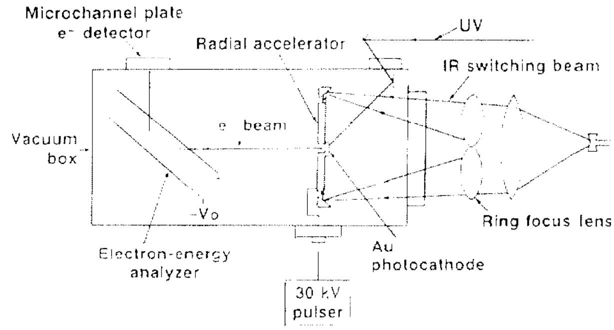

Figure 6: Schematic of electron acceleration setup.

some of the nonuniformity in the pulse spacing. In view of these difficulties we have proceeded to go on to the experiment of accelerating electrons with the structure. Such experiments should be free of these difficulties.

The electrons to be accelerated are generated from a gold coated saphire window mounted directly on the center hole of one plate of the accelerator. The electrons are created with 263nm UV from the same laser by frequency doubling a portion of the laser beam twice. The setup for this experiment is shown in figure 6.

Electrons from the accelerator are directed thru an electro static energy analyzer and onto a micro-channel plate (MCP) with a phosphor screen. As indicated in the figure everything is mounted in a vacuum box approximately 30cm × 30cm × 60cm. Not indicated on the figure are two deflection plates to steer the electron beam onto the entrance slit of the analyzer, and a focusing coil to colimate the beam. For 1500 volts applied to the acclerator the electron beam comes out with an angular divergence of about 100mr from a 1mm diameter hole. To perform the experiment the path lengths of the UV and the IR switching are adjusted so that the UV arrives to make electrons before the voltage pulse arrives at the center of the structure. The deflection plates and the electron energy analyzer are adjusted until electrons are observed on the MCP. The voltage on the energy analyzer is then scanned to display the spectrum of electrons generated by the accelerator. At this point electrons from the accelerator are observed over a wide distribution of energies primarily at or below the voltage applied to the accelerator, however electrons with gain are observed. We are currently developing a faraday cup with a charge amplifier to quantify this measurement. We are also exploring techniques to quantify and thus optimize the efficiency of the photoconductive switches, and we are looking into better methods of coupling the voltage pulse into the radial waveguide.

We wish to acknowledge the considerable efforts of Todd Blalock for constructing and maintaining the laser used for these studies, and we gratefully acknowledge the support of the Air Force Office of Scientific Research contract number AFOSR-87-0328 and the Department of Energy contract number DE-AC02-76ER13065.

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