A FIVE-PICOSECOND, ELECTRON PULSE FROM THE ANL L-BAND LINAC*

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The pulse-compression system of the Argonne National Laboratory Chemistry Division L-Band Linac, presented at the 1986 Linear Accelerator Conference at Stanford, California, has been completed. A five-picosecond-wide electron pulse containing 6 x 10^{-9} coulomb charge has been achieved. Acceleration parameters and the pulse-width measurement technique are discussed, and future plans for the utilization of this pulse in radiation chemistry studies are presented.

Introduction

The description of this system has been presented in Reference 1.

The system was designed to compress the 22-MeV pulse of 30 ps Full Width Half Maximum (FWHM) to pulse lengths of 5 to 6 ps with large peak currents of 1 x 10^3 A/pulse. This system became necessary in order to extend the study of reactive fragments of molecules to the time scale of a few picoseconds and, in particular, to examine the chemistry of electrons and ions before and during relaxation of the surrounding media. The 22-MeV electron linac uses a double gap 12th subharmonic pre-buncher followed by a one-wavelength 1.3 GHz traveling-wave prebuncher and a tapered buncher to produce a single pulse of 30 ps from one rf bucket, with an energy spread of $dE/E = \pm 0.5\%$ (FWHM) as shown in Figure 1. The pulse contains a long tail in the time domain and the same in the energy spectrum.[2]

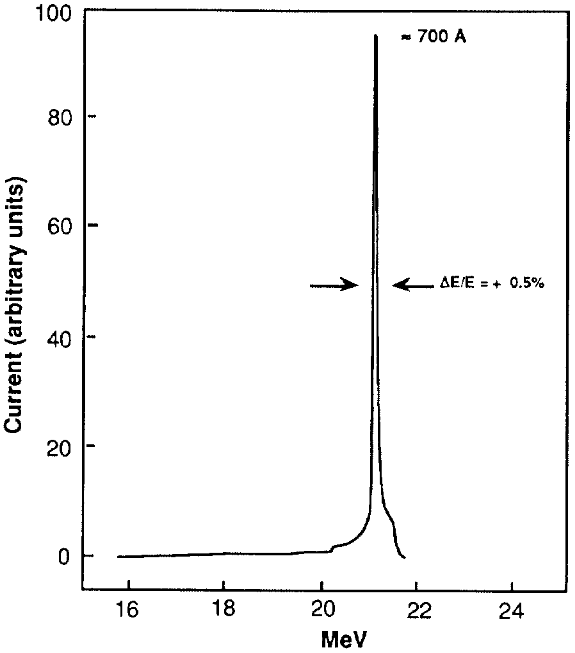

Figure 1. Energy spread of the 30-ps pulse $\frac{\Delta E}{E} = \pm 0.5\%$ (FWHM).

However, more than 80% of the electrons are within ±35 ps and $\frac{\Delta E}{E}$ of ±1%. The phase compression system required that the energy spread be increased considerably in order to rotate the ellipse, but fortunately the chemistry experiments are not sensitive to the beam energy spread $(\frac{\Delta E}{E})$.

Accelerator Parameters and Beam Measuring

The accelerator was tuned in such a way that the electron pulse was riding on the back slope of the traveling wave so that the front electrons were on the peak of the wave in both accelerating waveguides. The result of such a tune up was that the electrons within the pulse were oriented so that the higher energy ones were in the front and the lower energy ones in the tail of the pulse.

The beam exiting the accelerator is bent 90° by two 45° magnets with adjustable slits between them to control the energy spread of the beam as shown in Figure 2. Following a focusing quadrupole, the beam enters the bunching cavity which is an L-band waveguide identical to the accelerating waveguides of the linac. The value of the isochronous electric field in the bunching cavity is critical, and the rf power fed into it is controlled by a variable power splitter and phase shifter. A six-inch diameter circular magnet is placed just beyond the first 90° bending magnet, and it acts as a crude spectrometer. When the pulse is placed at the peak of the traveling wave in the bunching cavity, the peak field in that cavity is measured by measuring the maximum beam energy gain. Thus, the power splitter has been calibrated, and the readings are accurate and repeat well.

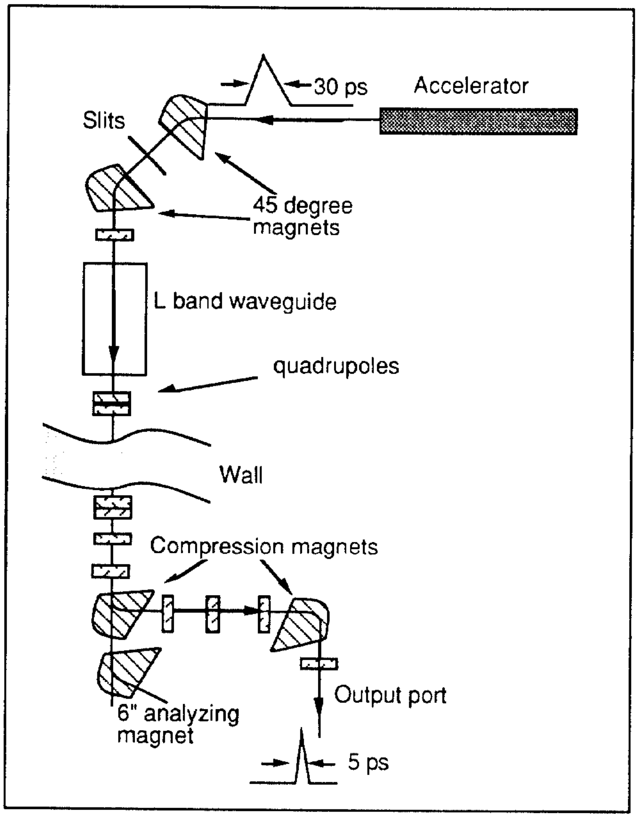

Figure 2. Beam transport system.

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By knowing the peak field in the bunching cavity, a pulse of known width (±15 ps or ±7.5°) placed in such a way that its center is in the 0° phase position, and its front towards the increasing voltage will emerge with an energy spread that is readily calculated $V = V_O \sin \theta$. In our case, the best results were obtained with a $V_O = 5.3$ MeV, thus a 30-ps pulse will emerge with $\frac{\Delta E}{E} = \pm 5.3 \sin 7.5° z = \pm 0.690$ MeV (FWHM), and this is roughly what it was expected to be.

Optical Measurements

The pulse width was measured using the same technique that has been previously employed in this laboratory[3]. The principle of the measurement is as follows. The electron beam irradiates a 5 cm suprasil cell which contains 1 atm xenon gas. The refractive index of xenon is sufficiently high so that Cerenkov radiation is created and exits the cell in a cone making an angle approximately 2.5 degrees to the beam. This light is then focussed onto the slits of a streak camera. The streak camera is used to measure the width of the pulse. The system is shown in Figure 3.

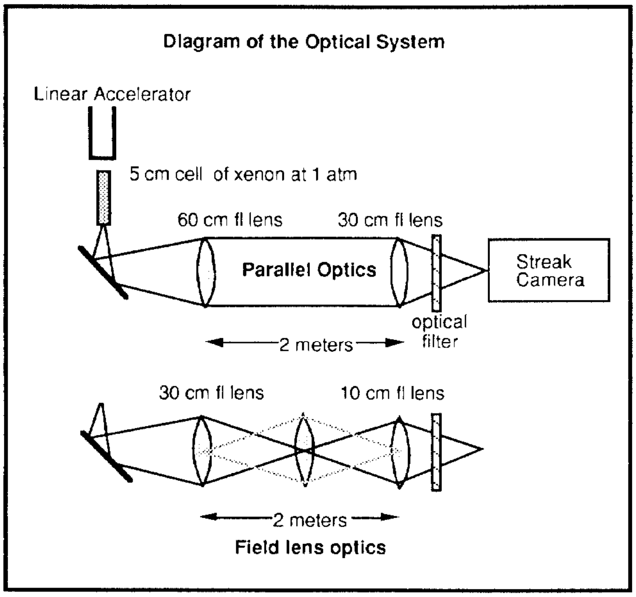

Figure 3. Optical system.

The Cerenkov was generated in xenon rather than in quartz so that most of the light could be collected and used for analysis. In addition, the scattering of the electrons is low in xenon so the angle at which the light comes is defined primarily by the incoming electron beam. Furthermore there is very little velocity difference between the electron beam and the generated light in 1 atm of xenon, which leads to a correspondingly negligible time spread in the the width of the measured Cerenkov pulse. In quartz the generated light travels approximately 30% slower in the quartz than does the electron beam.

Two optical transport systems were used to measure the pulse. Both were able to give good results. For the parallel optics, a defining slit was used at the cell to limit the region of light which can be transported to the streak camera. It was essential to limit the wavelength region of the light which strikes the streak camera. This was done using a 5-58 Corning glass filter which is centered at 410 nm and has a width of approximately 60 nm. If another broad-band filter which is peaked further into the ultraviolet is used or if no filter is used, the measured pulse width is broadened. This was attributed to the variation of the refractive index of the lenses over the wavelength range of light that was detected by the streak camera.

A Hamamatsu C1370-01 streak camera was used for the measurements. This streak camera has a time resolution of better than 2 ps. We used a slit width of approximately 7 μ. This slit width was chosen to keep the intensity low on the streak tube and thus avoid space-charge broadening in the streak tube. (A slit width of approximately 30 μ would not optically have limited our pulse width measurements.) The trigger for the streak camera was obtained from the pulse which triggered the electron gun. The jitter of the pulse detected by the streak camera was approximately 25 ps. This is due to both the jitter in the streak camera trigger and the jitter between the injector trigger and the RF of the accelerator. We did not attempt to improve upon this value.

Because the signal from the streak camera must be limited to avoid space-charge broadening in the measurement, there is considerable shot noise on the signal. To allow signal averaging, a program was written for the Hamamatsu computer to determine the position of the pulse. With this information, several pulses can be shifted and added together. A typical result is shown in Figure 4. Ten pulses were averaged. The slit width was decreased until the measured pulse width was constant. This was done to eliminate the space-charge broadening in the streak camera. Similar results were obtained on different days.

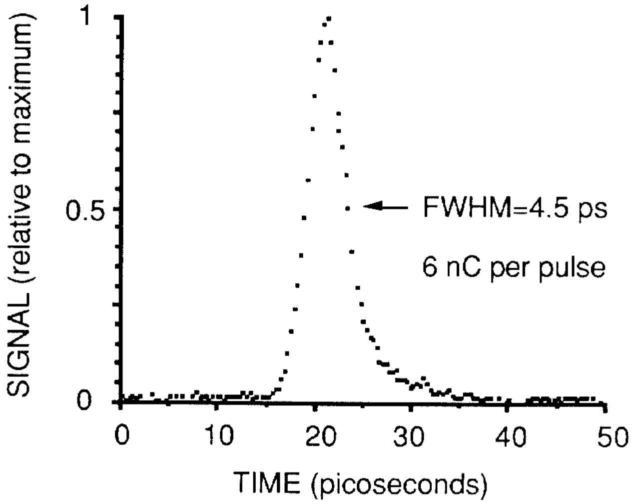

Figure 4. Relative light intensity vs. time for the Cerenkov light pulse created in 1 atm xenon. (Wavelength of light centered at about 410 nm, FWHM $\cong$ 60 nm.) Average of 10 pulses.

The critical factors for accurately measuring such short accelerator pulses are: (1) controlling the space-charge broadening of the streak camera; (2) controlling the region that is observed by the streak camera using appropriate focussing and field stops; (3) using xenon to tightly confine the light that is measured; and (4) selecting the wavelength that is observed to avoid broadening through wavelength dispersion in the lenses.

Uses of the 5-ps Pulse

The compressed pulse is currently being used to measure the recombination fluorescence which occurs when solutions of aromatic scintillators in dielectric liquids are irradiated. This fluorescence is due to the rapid scavenging of positive and negative charge by the scintillator molecule followed by ion-recombination which yields the lowest excited singlet state of the scintillator. The time dependence of the recombination fluorescence can be used to derive information about the ion chemistry of the solvent and the distribution of distances (from the sibling cation) of the electron ejected in an ionization event. This work is well underway and will be reported in a future publication.[4]

An apparatus is also being assembled in which the 5-ps pulse will be used in a pump-probe system for measurement of the optical absorbance of transient species in condensed-phase systems. This system is an extension of one used previously for similar measurements with a 30-ps electron pulse,[5] and will be used, for example, to study ultra-fast electron localization and solvation processes in alcohols.

Conclusions

In general, the future of the short pulses (5-6 ps) with high intensity > 1000 A belongs to the laser-excited photocathodes in conjunction with an rf source, but until reliable photocathodes are developed with long life and with reasonable vacuum requirements, the needs of the scientific community for very intense short pulses will be satisfied using the techniques described above.

References

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