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DEVELOPMENT OF LASERTRON AND LOW EMITTANCE ELECTRON SOURCE USING LASER TRIGGERED PHOTOCATHODE

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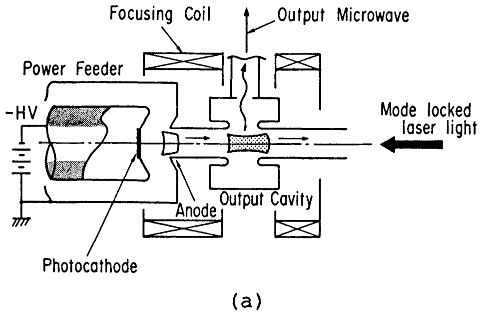
ABSTRACT A pulsed rf source, "Lasertron", and an rf gun using a laser triggered photocathode are being developed as a possible rf power source and an electron injector for Japan Linear Collider. Various type of photocathode such as GaAs and Sb-alkali are tested in order to obtain high current density of more than 100 A/cm^2 for a cathode with a radius of 1 cm. A frequency doubled mode-locked Nd:YAG laser system have been developed. The pulse width of a micro-pulse of 60 ps has already been achieved. The further improvement to realize a laser pulse with a width of around 10 - 20 ps is under progress.

INTRODUCTION

The lasertron[1,2,3] is proposed as one of the new rf sources expecting to generate an rf power of several hundred MW for future e+e- linear colliders, in which a laser-triggered photocathode is used. The beam is switched by a laser light whose intensity is modulated at an rf frequency as shown schematically in Figure 1(a). Since the time response of the photoemission process is in the range of ps or sub-ps, a bunched beam is emitted by a pulsed laser light directly on the cathode surface. The bunched beam is accelerated by the applied voltage between the cathode and the anode, and passes through the output cavity in which the beam power is converted to the rf power. The experimental study of the lasertron has been carried out for S-band rf frequency.[4] It has been found that the efficiency to convert the beam power to the rf power is poor because of the debunching effect due to the space charge force. On the other hand, it has been also proved that the photocathode can really generate the beam of high-current and high-current-density. These characteristics of the laser-triggered photocathode can be applied to the electron source of linear colliders. In the most linear colliders which are proposed recently,[5] it is necessary to accelerate multi-bunch beam of very high current in one rf pulse in order to achieve as high luminosity as 10^{33} $cm^{-2}s^{-1}$. Especially in case of the Japan Linear Collider, JLC,[6] the number of particles per bunch and the number of bunches per rf pulse are 1.0 x 10^{10} and 10, respectively, as listed in Table II. In this application of the laser-triggered photocathode, an rf acceleration of high gradient is necessary,[7] as illustrated schematically in Figure 1(b) to obtain the low-emittance-bunched beam. It can be also expected to realize high brightness because of its high current density.[8] Both of these characteristics are important for the linear collider.



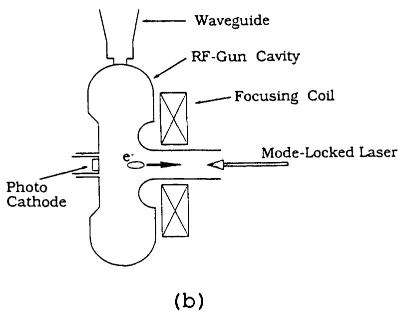


FIGURE 1 Schematic drawing of (a) a lasertron and (b) an rf gun using laser-triggered photocathode.

LASERTRON

The main parameters of the lasertron are summarized in Table I together with parameters of the laser system. Because the detailed descriptions of the experiment of lasertron are given in elsewhere,[4] only the outline of the study and the results are summarized.

The GaAs photocathode is used in the present study by considering as follows; (a) it is possible to produce a large cathode which has a high quantum efficiency as listed in Table I, (b) second harmonic of Nd:YAG laser can be used, and (c) the GaAs cathode can be revived even after the degradation of the quantum efficiency caused by the residual gas by applying heat cleaning to the cathode in the vacuum chamber, which helps to make the experiment repeatedly.

The laser is a frequency doubled mode-locked Nd:YAG which is composed of an oscillator, a waveform shaper, amplifiers, a second harmonic generator and a pulse multiplexer as shown in Figure 4. A long-flat topped pulse train of the pulses with the width of 60 ps has been obtained successfully[9] as shown in Figure 2.

TABLE I Parameters of the lasertron and the laser system

Lasertron	
Effective cathode radius	20 mm
Cathode-anode gap	20 mm
Effective cathode-anode gap	33 mm
rf frequency	2856 MHz
Pulse width	500 - 1000 ns
Pulse repetition rate	1 - 5 pps or single shot
Maximum applied accelerating voltage	150 kV
Maximum obtained beam current	20 A
Cathode material	NEA activated GaAs
Typical quantum efficiency	10 %
Laser system	
Laser	frequency doubled mode-locked Nd:YAG
Wavelength	532 nm (second harmonics of Nd:YAG)
Repetition rate	1 - 5 Hz or single shot
Width of micro-pulse	< 60 ps
Width of macro-pulse	500 - 1000 ns
Pulse rate	2856 or 178.5 MHz
Energy in pulse comb for 2856 MHz	20 mJ
Energy in pulse comb for 178.5 MHz	40 mJ
Energy variation of pulse comb	< 5 % rms
Flatness of the pulse comb	< 10 %/ 1 μs

Experimental results of the lasertron is shown in Figure 3. Beam current and rf output power are shown as a function of the applied voltage. Curves (a) and (b) in the figure correspond to the rf output power for the following two different configurations of the cavity; (a) the distance from the cathode to the cavity is 175 mm and (b) 60 mm. The maximum beam current and rf power obtained at the maximum voltage of 150 kV were 20 A and 80 kW, respectively. Thus the beam power was 3 MW and the efficiency was 2.6 %, which was very poor in comparing with the conventional klystron.

In order to simulate the beam dynamics in the lasertron, the bunched beam with a width of 60 ps is sliced into 12 disks by 5 ps steps and the beam motion is calculated.[10] The results for the accelerating voltage of 100 kV and the output current of 10 A are shown in Figure 3. It can be seen that the debunching of the beam which occurs in the low-energy region near the cathode surface is very severe. This fact causes the low efficiency of the lasertron. This effect becomes severe as increasing the distance of the output cavity from the cathode. Another problem of the lasertron is that the photocathode is damaged by an electron induced gas desorption which comes mainly from the beam collector. In order to avoid this problem, whole the beam should be guided to the beam collector and the conductance between the cathode area and the collector part must be reduced, which are inconsistent each other.

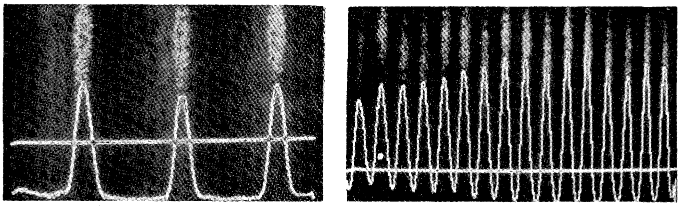
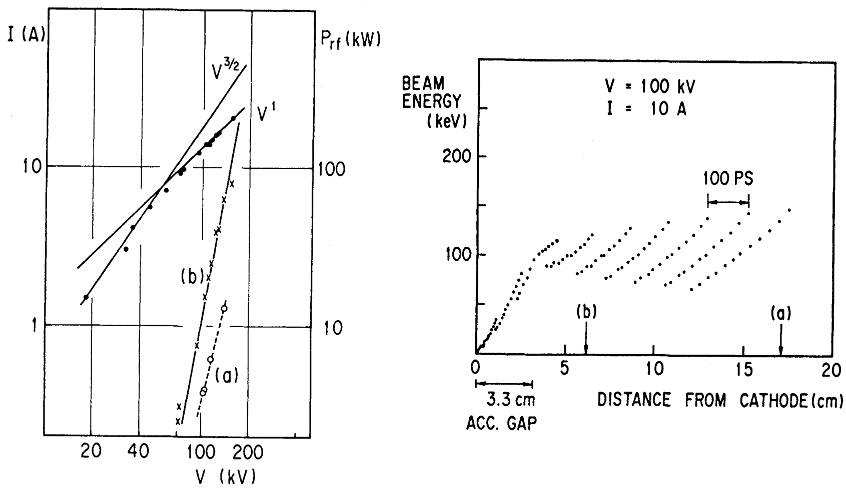


Figure 2 Photograph of laser pulses taken by a streak camera.



(a) (b)

FIGURE 3 (a) Experimental results. Beam current and rf output power as a function of the applied voltage. (b) Results of simulation of beam motion in the lasertron by the disk model for the accelerating voltage of 100 kV and the beam current of 10 A. The bunch is sliced into 12 disks indicated by a black dot in the figure. The energy and the longitudinal position of each dot are shown by 100 ps steps. The symbols (a) and (b) in the both figure give the two different positions of the output cavity as mentioned in the text.

RF GUN FOR LINEAR COLLIDER

As mentioned previously, high-current multi bunch beam is required to realize a high-luminosity linear collider. The beam parameters of

JLC are summarized in Table II and is shown in Figure 4. It is not easy to obtain such a bunch structure by using a combination of a conventional thermionic gun and sub-harmonic bunchers. On the other hand, the present experiment of lasertron shows that the photocathode can produce such a beam as listed also in Table II and is shown in Figure 4. In case of the laser-triggered photocathode, the bunch spacing can be controlled easily by using a mirror system as shown in Figure 5. The remaining problems to be solved to apply the present laser-triggered photocathode for the practical use as an injector of JLC are as follows; (a) the life time of the photocathode should be as long as several 1000 hours, (b) the pulse width of the micro-pulse must be reduced to 10-20 ps, and (c) rf acceleration is necessary to avoid the debunching due to the space charge effect as is observed in the lasertron.

TABLE II Beam parameters of JLC and experimental results of Lasertron.

	JLC	Lasertron
Number of particles per bunch	1.0×10^{10}	4.4×10^{10}
Number of bunches per rf pulse	10	2856
Repetition rate of rf pulse	200	1
Bunch spacing	1.4 ns	0.35 ns
peak current density	-----	40 - 80 A/cm^2

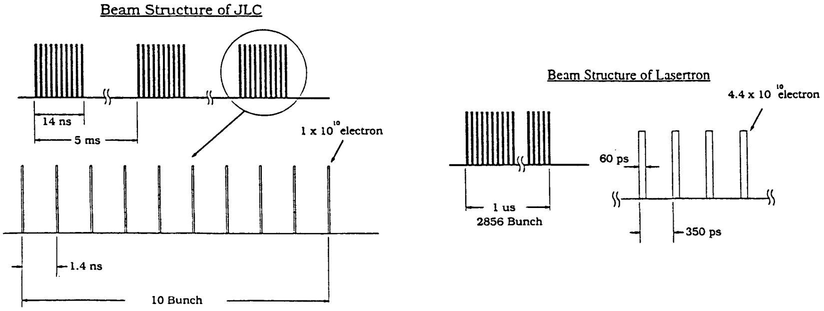


Figure 4 Required bunch structure of JLC and obtained bunch structure in the present lasertron.

The life time of the photocathode such as GaAs, Sb-Cs and Sb-multialkali are caused by the desorption of Cs from the cathode surface. The Los Alamos group has carried out the study of the photocathode extensively and found that Sb-K-Cs is promising.[11]

The pulse width of the present laser system of 60 ps can be reduced to 10 - 20 ps by adding a laser pulse compressor which consists of glass fiber and gratings, to the present laser system as is shown in Figure 5.

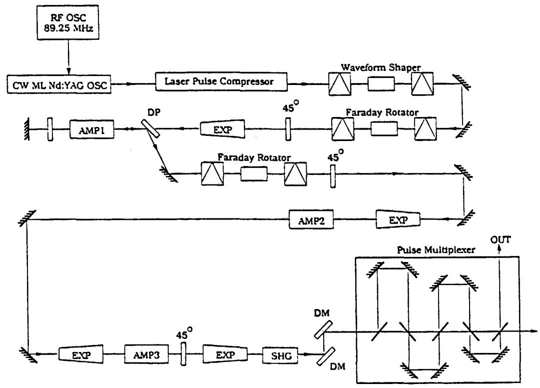


FIGURE 5 A block diagram of the proposed laser system to obtain the micro-pulse with a width of 10-20 ps. A pulse compressor system is added to the original laser system which is used in the experiment of the lasertron.

ACKNOWLEDGEMENT

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REFERENCES

1. M. T. Wilson and P. J. Tallerico, US Patent No. 4, 313, 072(Jan. 26, 1982)
2. P. Wilson, SLAC-PUB-2884(1982)
3. Y. Fukushima, T. Kamei, H. Matsumoto, H. Mizuno, I. Sato, T. Shidara, T. Shintake, K. Takata, Y. Kato, H. Kuroda, N. Nakano, H. Nishimura, M. Miyao, M. Mutou, M. Yoshioka and S. Takeda, Nucl. Instrum. & Methods. A238(1985)215
4. M. Yoshioka, Jap. Journal of Applied Physics, Vol. 28, No. 6 (1989) 1079
5. J. Rees and P. Wilson, Proc. of the International Workshop on Next-Generation Linear Colliders, SLAC-Report-335(1988)9
6. S. Takeda, paper contributed to this conference.
7. R. L. Sheffield, W. D. Cornelius, D. C. Nguyen, R. W. Springer, B. C. Lamartine, E. R. Gray, J. M. Watson, J. S. Fraser, paper contributed to 1988 Linear Accelerator Conference, Williamsburg, VA, U.S.A., Oct. 3-7, 1988.
8. C. H. Lee, P. E. Oettinger, E. R. Pugh, R. Klinkowstein, J. H. Jacob, J. S. Fraser and R. L. Sheffield, IEEE Trans. NS-32, No.5 (1985) 3045
9. M. Miyakawa, T. Harada, H. Imoto, J. Komatsu, T. Yakuo, T. Shintake, H. Matsumoto, T. Shidara and M. Yoshioka, Proc. of 12th Linear Accelerator Meeting in Japan, Aug. 24-26(1987)198, Nuclear Engineering Research Laboratory, Faculty of Engineering, Univ. of Tokyo.
10. T. Shintake, private communications.
11. W. D. Cornelius, private communications