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M. YOSHIOKA, T. NAITO, Y. OTAKE, K. TAKATA, Y. TAKEUCHI,
J. URAKAWA and H. AKIYAMA

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DEVELOPMENT OF AN RF GUN THAT USES A LASER-TRIGGERED PHOTOCATHODE FOR THE JAPAN LINEAR COLLIDER

M. Yoshioka, T. Naito, Y. Otake, K. Takata, Y. Takeuchi, J. Urakawa
KEK, National Laboratory for High Energy Physics,
1-1 Oho, Tsukuba, Ibaraki, #305, Japan
and
H. Akiyama,
Energy Research Laboratory, Hitachi, Ltd.,
1168, Moriyama, Hitachi, Ibaraki, #306, Japan

ABSTRACT

An RF gun using a laser-triggered photocathode has many advantages as an injector of linear colliders since it can generate a low-emittance high-current pulsed beam. An experimental facility for an S-band RF gun has been fabricated in order to study its fundamental characteristics. A beam comprising 175 pulses with the spacing of 5.6 ns has been successfully generated and accelerated with an accelerating gradient of 40 MV/m. The maximum energy and the number of electrons per bunch are 900 keV and 2×10^{10}, respectively. In this report we describe the RF gun as well as the experimental results.

1. INTRODUCTION

A low-emittance high-current beam is required for many accelerator applications, such as linear colliders and free electron lasers. For this environment RF guns have been studied in many laboratories[1,2,3]. At KEK, the Japan Linear Collider (JLC) is being vigorously pursued, with typical parameters corresponding to a c.m. Energy of 0.3~1.5 TeV and a luminosity of 10^{33}~10^{34}cm^{-2}s^{-1}[4]. The electron source of JLC must produce ~100 intense electron pulses with a spacing of 1.4, 2.8 or 5.6 ns for each cycle of operation with a repetition rate of 50~150 Hz. Each of these electron pulses must result in ~10^{10} electrons. An RF gun with a photocathode triggered by pulsed laser light could satisfy the above mentioned requirements, as schematically illustrated in Fig. 1 , in which the bunched beam can be generated directly on the photocathode. The photo-emitted current is accelerated with RF fields that are synchronized with laser pulses.

We have decided to start developing an S-band RF gun as part of the research and development program for the JLC, keeping in mind the following characteristics: (1) The accelerating gradient (Eacc) achievable with an RF field is much higher than that of a DC or pulsed field of conventional guns, making it possible to generate an extremely low-emittance, high-current beam. (2) Since the photocathode is triggered with a pulsed laser, a pulsed beam can be produced directly on the cathode without using any sub-harmonic buncher system. It is therefore easier to generate the beam for JLC using a mode-locked laser system and an optical system. (3) A higher current density can be generated by the photocathode than that by the thermionic cathodes.

On the other hand, there are several hurdles to be overcome for any practical use of the RF gun: (1) A stable laser system is required, which can generate laser pulses with an energy of 0.1 - 1 mJ per pulse with a short pulse duration of the order of 10 ps. (2) A high accelerating gradient must be generated in the cavity. (3) A photocathode is required which has a long lifetime and a high quantum efficiency (Q.E.), and can coexist with large RF fields and a high-power laser beam. (4) A low-level RF system should be developed, which could make it possible to synchronize the laser pulse precisely with the RF fields. (5) Beam diagnostics must be developed, and extensive studies concerning beam motion are required in order to understand the beam dynamics, since the behavior of a non-relativistic bunched beam is quite different from that of a coasting beam.

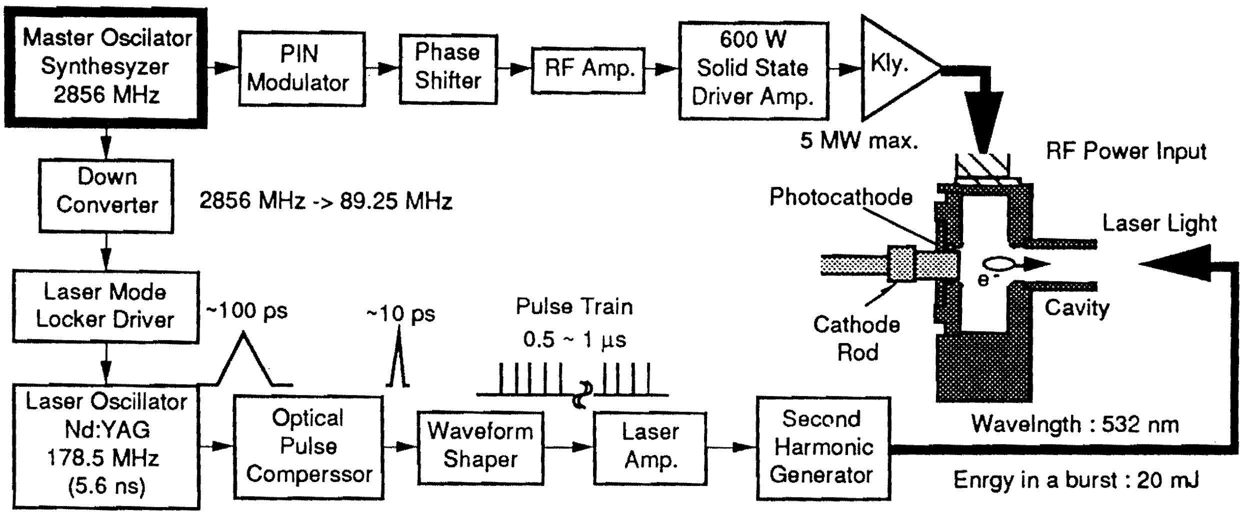

Fig. 1 Schematic Drawing for RF gun using laser-triggered photocathode.

In the following sections we describe the apparatus of the RF gun and the experimental results.

2. EXPERIMENTAL APPARATUS

As the first step of a study concerning the above-mentioned features, we have constructed the experimental facility shown in Fig.2, which features an accelerating cavity of the simple half-cell pillbox type at the S-band and comprising a photocathode, mode-locked Nd:YAG laser system developed for the Lasertron experiment[5] and high- and low-power RF systems.

2.1 Photocathode

We have chosen the Cs_3Sb photocathode, since it is easy to fabricate; also the Q.E. is high at the wavelength of the second harmonics of the Nd:YAG laser light (532 nm). In addition, damage of the photocathode in use *in situ.* can be revived repeatedly by applying the heat cleaning. Thin film of Sb is formed on a Ni rod with a diameter of 16 mm and the cathode is fabricated after heat cleaning at 600 °C. Cs vapor is applied just before the experiment. In the present experiment, however, the base pressure of the vacuum chamber is $\sim 7\times10^{-10}$ Torr. The procedure for cathode activation has not yet been optimized. The Q.E. and the lifetime are $10^{-3}\sim10^{-4}$ and 2.5 hours, respectively.

2.2 RF Cavity and High-Power RF System

In the present experiment, emphasis is being placed on studying the fundamental characteristics of beam motion in the RF gun at a high accelerating gradient and fabricating all of the key elements. A simple pill-box type cavity has been chosen in which the ratio of the maximum surface field to the Eacc is 1.29. For practical use in the future, the shape of the cavity should be designed so as to optimize from the view point of simultaneously obtaining low emittance and high Eacc.

We employed a mechanical RF contact by spring action instead of a choke structure in order to insure that the cathode rod maintain a stable contact with the cavity wall and that multipactoring is avoided. The cavity is tuned by adjusting the position of the cathode rod.

The applied accelerating gradient should be as high as possible in order to generate a low-emittance, high-current beam. However, the high electric field may induce a discharge or multipactor, which deteriorates the vacuum environment, the decreasing the lifetime of the photocathode. As a compromise between these two requirements we have established an Eacc of 40 MV/m as an initial target.

The RF power source is a pulsed klystron with a peak power of 5 MW and a pulse width of 2 μs, which has been operated at 5 Hz. The RF power is fed into the cavity through an iris window. The cavity has been processed up to an input power of 1.2 MW, this corresponds to an Eacc of 50 MV/m prior to the experiment. During the experiment at an Eacc of 40 MV/m, no RF breakdown was observed and the pressure of the cavity was around 1×10^{-9} Torr.

2.3 Low-Level RF System

Regarding the RF gun, the phase between the input laser pulses and the RF fields must be synchronized precisely. The frequency of the laser system is the 32nd subharmonic of the RF field. The phase jitter between these two frequencies should be decreased so as to be as small as possible. As shown in Fig.1, the master oscillator of the entire system is a synthesizer with a frequency of 2856 MHz, which generates the input signal for the klystron. After pulse modulation with a pin-diode, the signal is amplified with a solid-state amplifier and fed to the klystron. A signal for an acoust-optical (AO) modulator of the laser system, whose frequency is 89.25 MHz, is generated from this 2856 MHz signal with the frequency down-converter circuit. Using this method, the phase jitter between the two frequencies can be reduced to 10~20 ps.

2.4 Laser

The oscillator of the laser is a CW mode-locked Nd:YAG laser with a wavelength of 1064 nm, a power level of 4 W and a frequency of 178.5 MHz, which corresponds to a pulse spacing of 5.6 ns. The width of the each pulse is about 100 ps at the output of the oscillator; it is compressed to a shorter pulse of about 10 ps with an optical pulse compressor comprising an optical fiber and a grating pair. A pulse train with a width of 0.5 ~ 1μs is formed from the CW laser pulses with the wave form shaper[5]. After that, the pulse is amplified in one double-path amplifier and two single-path amplifiers. Finally, the 1064nm wavelength is converted to 532nm with a second-harmonic generator (KD*P). The laser light is guided onto the photocathode in the cavity with a mirror system. A picture of the pulses taken using a biplanner tube whose rise time is 65 ps is given in Fig.3. A detailed picture of the laser pulse

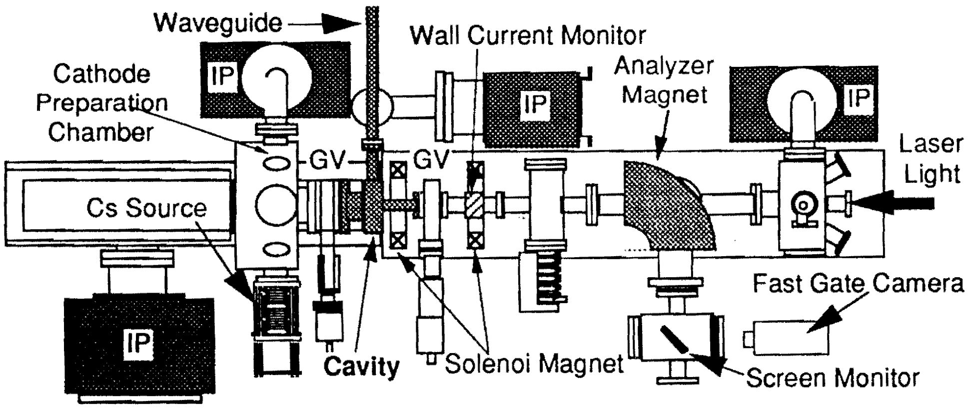

Fig. 2 Experimental Apparatus of RF gun, GV : gate valve, IP : ion pump

was taken by a streak camera with a time resolution of 2 ps (Fig.4). The energy of the laser is ~0.15 mJ/micro-pulse. Unfortunately, a large phase jitter of ~100 ps occured in the present experiment due to vibration of the AO-modulator and the laser-rod in the oscillator due to the cooling water.

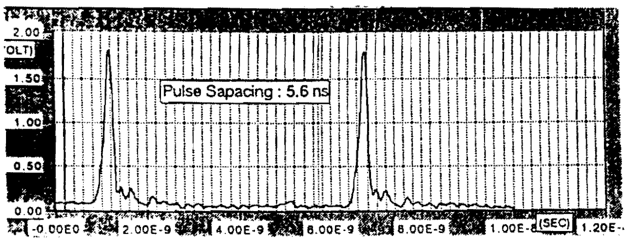

Fig. 3 Picture of the laser pulse detected by a biplanner tube

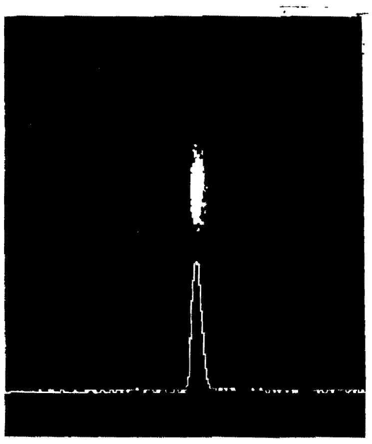

Fig. 4 Picture of the laser pulse observed with a streak camera: pulse width 12.5 ps at FWHM.

3. Experimental Procedure and Results

The photocathode was actived in the preparation chamber and then inserted to the cavity. The cathode position was determined so as to tune the resonant frequency by observing the reflected RF power from the cavity at 2856 MHz. Finally, the laser was fired by a single-shot mode, the pulse shape of the beam current was observed by the wall current monitor whose rise time is 100 ps, as recorded on a digital oscilloscope. A typical wave form of the extracted beam is shown in Fig. 5 with the RF signal used as a reference. It can be clearly seen that the photo-emitted current is extracted at every 16 RF pulse. The maximum number of electrons contained in one micro-pulse has been estimated to be $2x10^{10}$, resulting in $3.5x10^{12}$ per shot, since the width of the pulse train is 1 μs. The maximum energy of the beam was measured to be 900 keV at an Eacc of 40 MV/m with a magnetic analyzer (Fig. 2). The profile of the analyzed beam on the screen monitor is recorded with a fast gate camera with increasing the field of the analyzer magnet.

After accumulating data for many beam shots, the maximum energy was determined since the relative phase between the laser pulse and the RF field could not be precisely determined as described in the previous section.

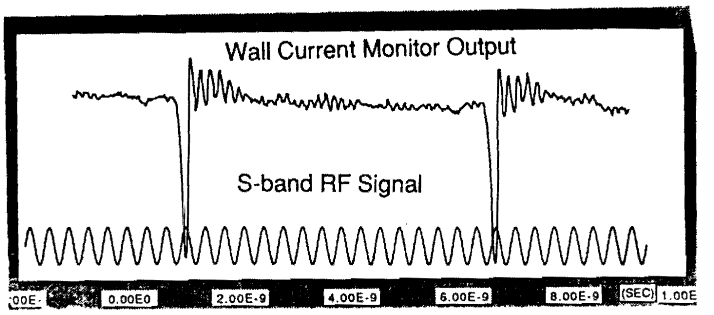

Fig. 5 Picture of the extracted beam of the RF gun

4. SUMMARY

We have successfully generated a pulsed beam with an S-band RF gun using synchronization between the laser pulse and RF fields. The maximum number of extracted electrons is $2x10^{10}$/micro-pulse and $3.5x10^{12}$/shot; these are limited by the performance of the cathode. The maximum beam energy at an Eacc of 40 MV/m is 900 keV, which is consistent with beam dynamics analysis. Further experiments are necessary in order to study the beam dynamics in detail: measurements of the emittance and bunch length as a function of Eacc and the relative phase between the laser pulse and RF fields.

The key technologies to develop practical RF guns are as follows:(1) the necessary development of a stable laser system and (2) fabrication of a photocathode with a long lifetime at a high Q.E. Requirement (1) can be realized by adopting a solid state laser system which uses a laser diode. In the present experiment, the performance of the Cs_3Sb photocathode was mainly limited by the desorption of Cs from the cathode surface. A mechanism to supply Cs onto the cathode should be developed in order to satisfy the requirement (2).

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References

[1] J. Fraser et al., "High-Brightness Photoemitter Injection for Electron Accelerator", Particle Accelerator Conference, p. 1791, 1985

[2] Y. Baconnier et al., "A CLIC Injector Test Facility", CLIC Note 65, 1988

[3] K. Batheleor et al., "The Brookhaven Accelerator Test Facility", Particle Accelerator Conference, 1989

[4] K. Takata, this proceedings.

[5] M. Yoshioka, "Lasertron : A Pulsed rf Source Using a Laser-Triggered Photocathode", JJAP, Vol.28, No.6, June 1989, pp.1079 - 1093