LASERTRON, A PHOTOCATHODE MICROWAVE DEVICE SWITCHED BY LASER*

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We study a new rf-source, LASERTRON, aiming to apply it for future very-high-energy e^+e^- linear colliders. We started a research and development program to construct a LASERTRON with a peak rf-power of 50 MW by using GaAs or GaAsP photocathode as a first step to achieve GW. Design studies and preliminary experiments are described.

Introduction

A conceptual drawing of the LASERTRON is given in Fig. 1 [1]. Mode-locked laser light, whose intensity is modulated at the rf-frequency, irradiates the photocathode. The photo-emitted beam is accelerated towards the output cavity by the applied voltage between the cathode and the anode. The beam is bunched at its source and the rf-power is extracted out from the cavity.

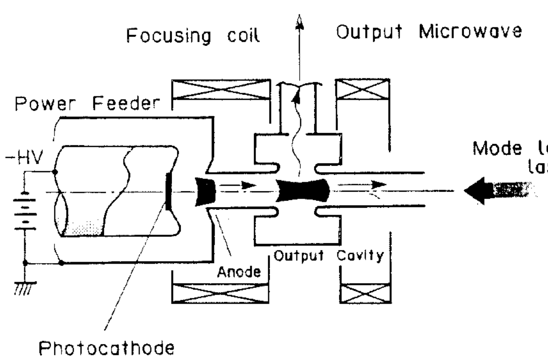

Fig.1 A conceptual drawing of the LASERTRON.

A prototype of the LASERTRON Mark-I, was fabricated and the rf-power was generated successfully[2]. This model of seal-off type has a conventional Sb-multialkali photocathode with a quantum efficiency of 3% for green light. We obtained the maximum output rf-power of 1.6 kW. This limitation is mainly due to the breakdown of the accelerating voltage at 30 kV, which is unavoidable for this type of photocathode because the work function of the whole inner surface of the tube is lowered by the alkali vapor.

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Extending these studies, we started a new research and development project aiming to construct a LASERTRON with a peak power of 1 GW using other types of cathode material. As a first step, we plan to construct a LASERTRON of 50 MW, so called "LT300", with GaAs or GaAsP photocathode. The parameters of LT300 are listed in Table-1. In this paper, we will describe the results of the design study and the preliminary experiment on the photocathode.

Table-1; Main Parameters of LT300

Output rf-Power (Po)	50 MW (peak)
Efficiency	50 % (assumed)
Pulse Length	1 us
rf-Frequency (f)	2856 MHz
Cathode-anode Voltage (V)	300 kV
Cathode Diameter	4 cm
Cathode Area	12.6 cm^2
Cathode Capacitance (C)	0.37 pF
Critical Charge (Qc)	110 p coulomb
Cathode-anode Distance	3.0 cm
Field Gradient	100 kV/cm
Beam Impedance	1 kΩ
Average Beam Current (I)	310 A (in 1 μsec)
Current Density	25 A/cm^2
Cathode Material	GaAs or GaAsP
Quantum Efficiency	5 - 10 %
Average Laser Power	10 kW (in 1 μsec)
Wavelength of Laser Light	530 nm
Repetition Rate	10 Hz

Beam Dynamics

The maximum output power of the LASERTRON is determined by the output current from the cathode. The current limit is due to the space charge effect when the cathode is irradiated by the laser with enough power. The maximum charge per pulse which can be emitted from the cathode is called critical charge, Qc, and is given by

$$Qc = C \times V, \tag{1}$$

where C and V are the capacitance and the applied voltage between the cathode and the anode, respectively. Then the average current, I, is given by

$$I = f \times Qc, \tag{2}$$

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where f is the rf-frequency. Then the rf-power, Po, is given by

$$Po = k1 \times k2 \times I \times V$$

$$= k1 \times k2 \times f \times C \times V^2, \qquad (3)$$

where k1 is the efficiency in transfering the stored energy in a power-supply to the beam energy and k2 is the efficiency in transfering the beam energy to the rf-energy.

It should be noted that the electron beam is bunched at its source and therefore it induces wake fields between the cathode and the anode. Consequently, the beam loses a part of its energy and the bunch shape is deformed. Because the analytic calculation of wake fields is difficult and the computer codes for a klystron cannot be applied directly to this case, it is necessary to develop new computer codes to simulate the beam dynamics and calculate k1 and k2.

Two codes named PACOL[3] and FCI[4] have been developed in parallel in order to compare their results each other. They calculate the interaction between the non-relativistic electron beam and electromagnetic fields in the cavity structure self-consistently, where the cylindrical symmetry is assumed. Fig. 2 shows an example of the simulation of the beam motion between the cathode and the anode of LT300 by use of FCI code, where the beam current of 60 A is assumed. Now the improved versions of the code, which calculate the effect of the external magnetic field along the beam axis, are being prepared.

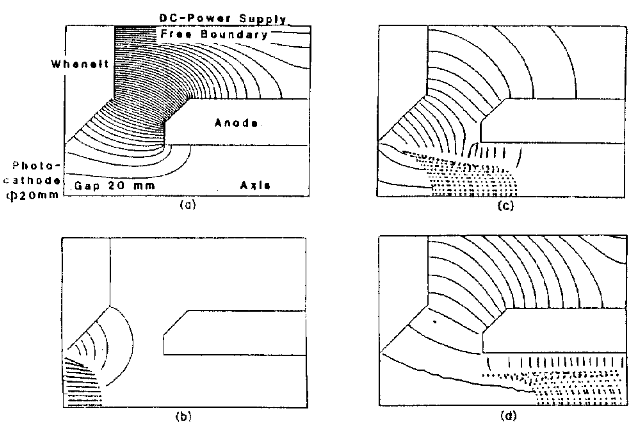

Fig.2 Beam simulation by FCI code for LT300 with the accelerating voltage of 300 kV and the beam current of 60 A. (a)External electric field only. (b) t = 100 psec, where t is the time after the laser illumination.(c) t = 200 psec.(d) t = 300 psec.

Photocathode

Cathode Material

Fig. 3 shows the relation between the wavelength of light and various photocathode materials. The photocathodes with the quantum efficiency of greater than 10 % and 5 - 10 % are shown by bold lines and fine lines, respectively. The requirements for the optics to guide the light are given at the bottom of the figure. As shown in the figure, the metal cannot be used as the cathode material of the LASERTRON because the mode-locked laser with the wavelength of less than 100 nm is not yet available and the requirements for the optics is too hard to realize. The Sb-alkali cathodes do not fit to LASERTRON too because of the breakdown problem as described in the first section. Therefore, we decided to choose GaAs or GaAsP with negative electron affinity (NEA) as a cathode material of LT300. The characteristics of these cathodes are summarized as follows;

(a) It is easy to obtain the quantum efficiency between 5 and 10 % for green light.

(b) The life of this cathode is short in comparison with that of Sb-alkali cathodes because the cesium is not contained in the cathode itself. However, it can be re-activated easily.

(c) It is expected that the high accelerating voltage can be applied without breakdown because the balanced vapor pressure of the cesium is low.

(d) Because the electric conductivity of a high-doping p-type crystal is high, the high current beam can be extracted from the cathode.

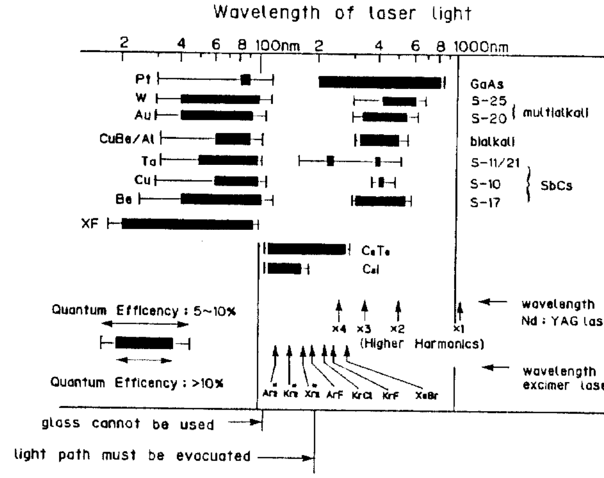

Fig.3 The relation beteween the quantum efficiency of the photocathode and the wavelength of light.

Test Bench of the Cathode

A vacuum chamber for the preparation and the test of the cathode has been fabricated as shown in Fig. 4. We aim to study the following items by using this system;

(a) the technique to obtain the high quantum efficiency and long life time,

(b) the procedure to reactivate the cathode which is damaged by the residual gases,

(c) the method to apply the high accelerating voltage without breakdown.

The main components of the chamber are an inner conductor in which an electron-bombarding equipment to heat the cathode is contained, an outer conductor, a high voltage feedthrough, cesium and oxygen sources, a window for laser-illumination and an evacuation system.

Preliminary Experiment

The study of the preparation technique

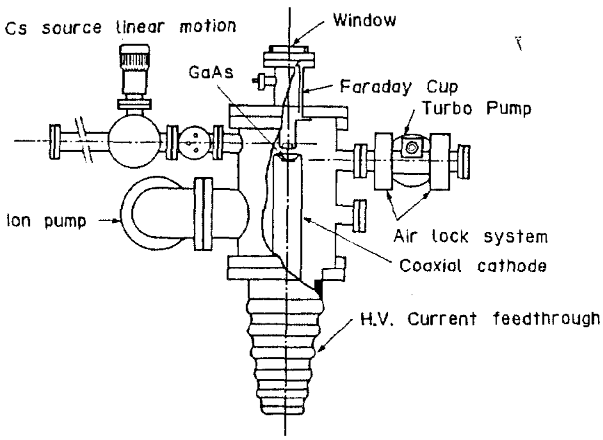

Fig. 4 A cross sectional view of the vacuum chamber for the test of the cathode.

and the activation condition for GaAs surface has been performed. The preparation of the cathode in the LASERTRON and the test to apply the high accelerating voltage are now going on. The activation process of GaAs is as follows. A GaAs wafer is heated at 550° - 600° C in the ultra-high vacuum for 10 - 30 minutes. We put the cesium and oxygen vapor into the chamber successively to be adsorbed on the GaAs surface. We repeat this procedure a few times. A typical photo-responce during the adsorption of cesium and oxygen is shown in Fig. 5. It is very important to control the procedure of the cesium activation because an excessive cesium causes the high voltage breakdown. We supply the cesium only on the surface of the GaAs and remove the cesium source after the activation, then the cesium vapor pressure becomes very low after the activation. The balanced cesium vapor pressure of NEA GaAs is an order of 10^{-14} torr at the temperature of 20° C and becomes 10^{-12} torr at the temperature of 50° C. Therefore, the photosensitivity of NEA GaAs is strongly affected by the cathode temperature, which is shown in Fig. 6. The marks A - E in the figure correspond to the marks in Fig. 5. We estimate from the evaporation rate of the cesium that the life time is 10^5 hours at 20°C and 10^3 hours at 50°C under the ideal condition without any residual gases. We have already achieved the breakdown voltage of 70 kV under the anode-cathode distance of 7 mm after the NEA activation.

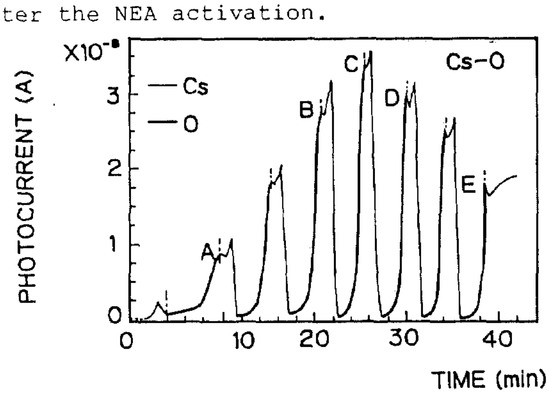

Fig. 5 Photo-responce of the GaAs cathode during the activation process.

Laser

A conceptual design of the laser system, whose main parameters are listed in Table-1, has been completed and its block diagram is shown in Fig. 7. The oscillator consists of a mode-locked YAG laser at the frequency of 95.2 MHz. The width of one pulse is 60 psec and the peak power is 1 kW. These continuous pulses are chopped into bunches with the width of 1 μsec and the repetition of 10 Hz by a pockels cell. Then they are amplified up to 1 MW. The time interval of the laser pulses is converted from 10 nsec to 350 psec by a combination of half mirrors. Finally, the wavelength of the laser light is converted by use of a KD*P crystal from 1.06 μm to 0.53 μm.

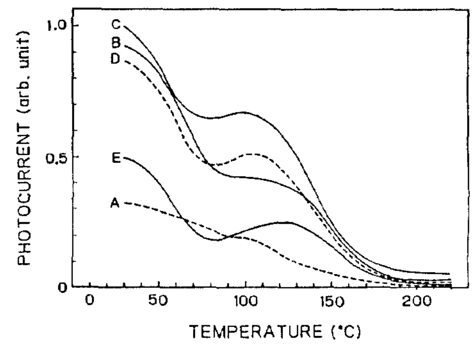

Fig. 6 Temperature dependences of the photo-responce. The lines A - E corespond to the peaks A - E in Fig. 5.

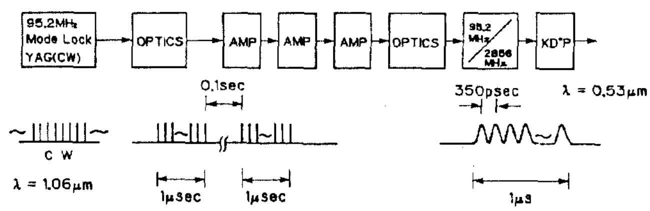

Fig. 7 A block diagram of the laser system for LT300.

Conclusion

The preparation technique and the activation condition of GaAs cathode have been studied and it is shown that the GaAs cathode is promissing for LASERTRON. Now the calculation of beam dynamics, the diode test, and the construction of laser system are being continued for LT300, whose designed peak rf-power is 50 MW.

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