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AN EXPERIMENTAL PROGRAM TO BUILD A MULTIMEGAWATT LASERTRON FOR SUPER LINEAR COLLIDERS[*]

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SUMMARY

A lasertron (a microwave "triode" with an RF output cavity and an RF modulated laser to illuminate a photocathode) is a possible high power RF amplifier for TeV linear colliders. As the first step toward building a 35 MW, S-band lasertron for a proof of principle demonstration, a 400 kV dc diode is being designed with a GaAs photocathode, a drift-tube and a collector. After some cathode life tests are made in the diode, an RF output cavity will replace the drift tube and a mode-locked, frequency-doubled, Nd:YAG laser, modulated to produce a 1 us-long comb of 60 ps pulses at a 2856 MHz rate, will be used to illuminate the photocathode to make an RF power source out of the device. This paper discusses the plans for the project and includes some results of numerical simulation studies of the lasertron as well as some of the ultra-high vacuum and mechanical design requirements for incorporating a photocathode.

INTRODUCTION

The lasertron R&D program at SLAC resulted from an interest in finding an efficient, high-peak-power, microwave amplifier for use with super linear colliders. The current state of the art in klystron amplifiers at SLAC is 150 MW peak at about 50% efficiency from a 465 kV beam[1], but higher peak powers are required for super linear colliders and higher efficiencies are desired. Klystrons use velocity modulation to produce bunching of the electron beam. This process becomes increasingly more difficult, although not impossible, as the beam becomes more relativistic.[2] In a lasertron the emission from the photocathode is modulated and then this modulated current is accelerated. Thus the lasertron can be considered a current modulated device, analogous to a triode in which the grid and the cathode are in intimate contact. The "grid" or photocathode surface is driven by an amplitude modulated photon beam, which releases electrons in proportion to the number of incident photons. The lasertron has an output cavity and collector similar to those used in a klystron.

The surface charge stored on the cathode due to its potential and the cathode-anode capacitance gives a measure of the maximum charge available per bunch. The motion in the cathode to anode region of the charge that is emitted from a lasertron's photocathode in a fraction of an RF cycle is not amenable to a Pierce-type, space-charge-limited, gun analysis.[3] Thus, a calculation of the charge density and energy spread, as a function of time and position through the tube, requires the use of an electromagnetic, relativistic, particle-in-cell program like MASK[4] to account for the significant self-inductive and longitudinal space charge forces involved.

M. T. Wilson and P. J. Tallerico of LASL have a patent[5] on the lasertron idea. Also, a group in Japan has built a low power (1.6 kW pulsed) lasertron[6] and are working now on higher power tubes. Current work at SLAC on photocathodes[7] for linac injectors and the existence of a high power klystron developmental program[1,8] has provided the technology to start an experimental and computational design study, which will lead to a proof of principle test of a high power lasertron in early 1986. This test should help determine whether the lasertron is a viable candidate for the RF amplifiers for super linear colliders. This paper is divided into two parts: first, computations of the optics based upon known tube design techniques and the special characteristics of pulsed photocathodes and second, the design of a proof of principle tube and the experimental program planned to investigate characteristics of this tube.

COMPUTATIONS

Figures 1 and 2 show the results of a MASK computation for a test diode, which takes into account space charge and self-inductive forces. In order to make laser illumination of the photocathode from the collector straightfoward, a planar cathode is used with an anode hole and drift tube of comparable size. This geometry requires an axial magnetic field to confine the beam. Specifically, Fig. 1 shows the results of radial and longitudinal debunching of the beam as a function of position through a diode and Fig. 2 shows the bunched-beam energy spread for two bunches. The first one is being accelerated and the second one is past the anode and is drifting toward the collector.

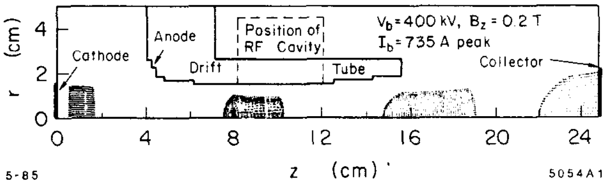

Fig. 1 - MASK computation of the bunched beam charge density for a diode(cathode-anode, drift tube and collector), as a function of radius, r, and distance from the cathode, z. Shown are four pulses out of a continuous train, in four sequential positions from the cathode through the drift tube and on to the collector. Each pulse is emitted from the photocathode over a 60 ps time period. The pulses occur at 350 ps intervals, corresponding to a 2856 MHz rate. For this example, the cathode to anode voltage is 400 kV, the peak current in a pulse is 735 A and a 0.2T axial magnetic field is used. The average current is 126 A and the beam power is 50 MW.

Simulations not shown here predict that it is possible to achieve about 50% efficiency in converting 50 MW of beam power to RF power if a single RF output cavity and gap are used with a 400 kV cathode potential and the geometry shown in Fig. 2. However, if a double output cavity gap (two cavities magnetically coupled and tuned for the 2π-mode) is used, an RF conversion efficiency of about 70% should be achievable

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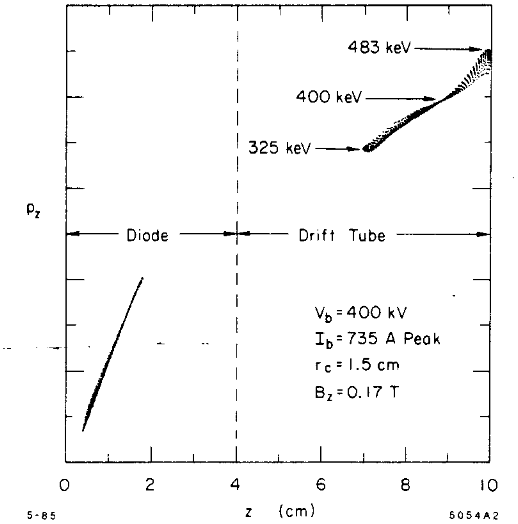

Fig. 2 - MASK computation of longitudinal momentum, p_z, versus distance from the cathode, z. The tail of the first pulse is out of the diode accelerating region, thus the energy spread between the front and the back of the bunch is representive of that of the bunched beam before it enters an RF cavity. The normalized fundamental harmonic component of the pulse train, I_1/I_0, is greater than 1.5.

for the same operating conditions. Other configurations might result in even higher efficiency for the lasertron.

DESIGN AND EXPERIMENTS

For the first experimental tube we have chosen the parameters listed in Table 1.

Table 1. Parameters for the Lasertron
Proof of Principle Tests

Peak RF Output Power	35 MW
Beam Power	50 MW
Efficiency	70 %
Voltage	400 kV dc
Peak Pulse Current	735 A
Cathode Diameter	3 cm
Average Pulse Current ($\simeq$ Peak/6)	126 A
Optical Pulse Length	60 ps FWHM
Optical Pulse Separation for a 2856 MHz Rate	350 ps
Microwave Pulse Length or Optical Pulse Train (Comb) Length	1 μs
Average Power (Power Supply Limited)	< 4 kW
Peak Electric Field in Gun Region	< 15 MV/m
Electric Field on Planar Cathode	10 MV/m
Maximum Magnetic Focussing Field	0.2 T

The design goal of 35 MW of peak RF power at 70% efficiency was chosen to be sufficiently high to make the first tube a reasonable, scaled-down version of the desired tube for super linear colliders. The tests are planned in two steps. First, a diode is being built and will be tested using nanosecond pulses from an available laser. When these tests are completed and when the microwave modulated laser is delivered, an RF cavity will replace the drift tube as shown in Fig. 3 and the tube will be tested for its RF performance.

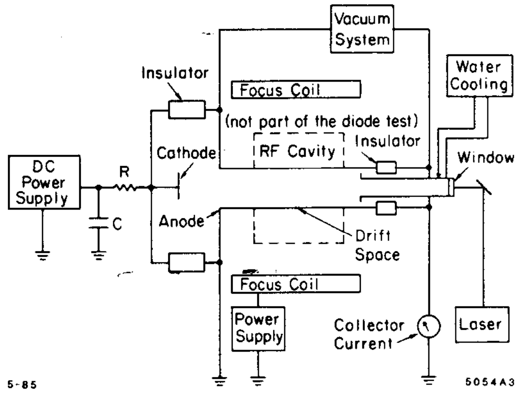

Fig. 3 - Schematic diagram of the lasertron circuit for diode and RF tests.

The design philosophy followed for the proof of principle tests is to use standard parts and techniques wherever consistent with the lasertron's requirements. A commericial high-voltage, switch-tube ceramic will be used in the gun area along with numerous conflat flanges throughout as shown in Fig. 4.

Pressurized sulfur hexafluoride was chosen for the insulating material to surround the cathode ceramic in order to avoid the use of oil. A 400 kV dc power supply and a polyethylene-insulated high voltage cable, which doubles as a storage capacitor, will be used instead of a modulator. The dc standoff problems are not easy even at this voltage, so at higher voltages a pulsed power supply might be needed. An arc-energy absorbing resistor (75 ohms) will be used in series with the 50 ohm high voltage cable as shown in Fig. 5. Figure 6 is a block diagram of the mode-locked laser.

Since the photocathode must be kept under vacuum after activation, a cesium source, shutters and gas leak valves are being built into the experimental tube. Typical steps in the tube bakeout and photocathode activation processes are as follows. The entire tube is baked out and is allowed to cool. Immediately prior to activation, the cathode surface is further cleaned by selectively heating it to several hundred degrees Celsius and then cooling it. The gallium arsenide photocathode is activated by adding monolayer quantities of an alkali metal (typically, cesium) and an oxidant (typically, oxygen or fluorine). The cathode activation is monitored by measuring the photocurrent produced by white light illumination and the application of a few tens of volts to the cathode. If the tube vacuum is not broken, multiple cathode heat cleaning and activation cycles may be accomplished, as required. The activating chemicals are introduced into the cathode area by bellows retractable probes. A capability is being built into the tube to allow subsequent bakeout of the collector only, or of the collector at a higher temperature than the rest of the tube body, if desired.

The ultrahigh vacuum requirments of the photocathode are reflected in the design of the collector, which is surrounded by a 600 ℓ/s non evaporable getter (NEG) pump (see Fig. 4). This pump can be reactivated by running current through its elements and letting the ion pumps take up the evolved gas. An experiment to study the electron induced desorption effects

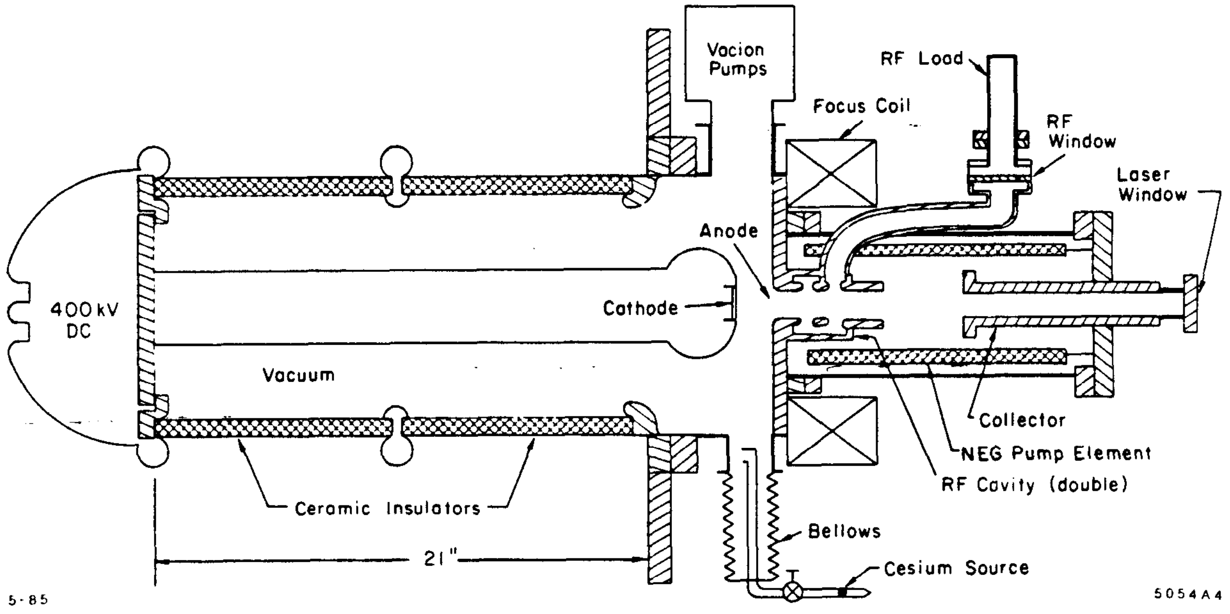

Fig. 4 - Cathode to collector geometry for the lasertron.

in various possible collector materials is underway. Various pulse current transformers, RF coupling loops and probes will be used to monitor the peak current and explore tube geometry related RF resonances and any other instabilities encountered. Standard instrumentation will be used to monitor the vacuum outgassing products and detect any high voltage processing arcs.

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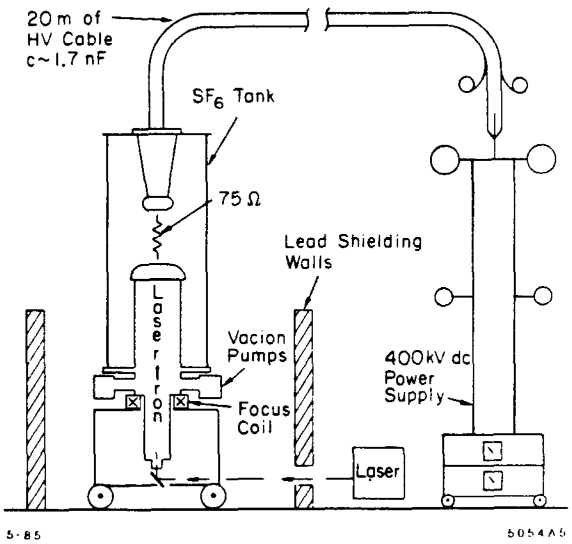

Fig. 5 - Lasertron experimental setup showing the -400 kV dc power supply, laser, lead shielding wall, high voltage cable (and storage capacitor), cable bushing, arc-energy absorbing resistor and the lasertron in its sulfur hexafluoride tank and mounted on a cart.

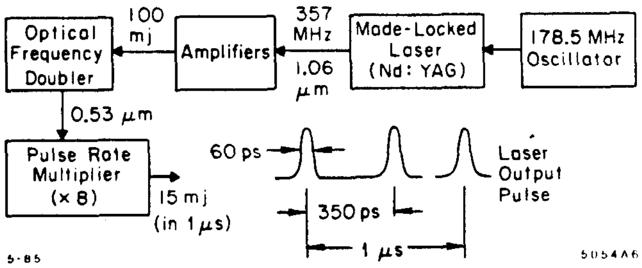

Fig. 6 - Block diagram of the laser which will be modulated at 2856 MHz and will be needed for RF tests of the lasertron.