ADVANCED ACCELERATOR R & D AT LAL/ORSAY

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Summary

An R & D programme was launched at LAL, ORSAY at the end of 1985 as a contribution to the future of e^+e^- linear colliders.

This programme includes beam dynamics simulation, generation of short pulse high peak currents, Lasertron type RF power source, and high gradient warm structures.

To fit with the experimental programme, two test facilities have been built and are now operating : a 3 GHz high gradient test facility with beam, and a photocathode test facility.

A description of the facilities will be given, as well as the first experimental results.

I Introduction

Though noticing that it is desirable to go to higher RF frequencies for future linear accelerators to increase the power efficiency, it is believed that still much development can be done at the standard frequency where power sources and instrumentation exist.

Quite high accelerating gradients have been obtained in different places on SW cavity samples [1,2] but operating an accelerator under such condition still remained to be done.

The test facility, at LAL, can provide a bunched beam at 3 GHz and at an energy of 4 MeV which can then be accelerated through any accelerating structure under high gradient test. The facility comprises also a modulator-klystron with an RF peak power of 37 MW, and the necessary beam instrumentation for beam dynamics tests. Up to now two different types of TW accelerating structures have been experimented with beam at a gradient level less or equal to 30 MV/m.

The relatively recent interest about laser triggered RF sources, better known as Lasertron [3-5], led up LAL to design a 6 GHz prototype Lasertron. A computer code named RING [6] was written to simulate the dynamics, under space charge conditions, of short and high peak current bunches photo-emitted and accelerated in the gun part of the Lasertron. An improved version of the code, named OAK [7], can handle RF cavities such as the extraction cavity. It can be also used for designing RF guns.

The experimental work on the Lasertron started with photocathode studies and led to build a specific test facility. This facility comprises an ultra high vacuum gun region fed by a 150 kV d.c. power supply, and a high voltage tank with freon at normal pressure, matched to 50 ohms to avoid resonances under short pulse photoemitted current. Presently the facility is operated with no extraction cavity. Instead of this cavity one uses short pulse instrumentation such as broadband coaxial faraday cup or transient radiation monitor, in order to study the dynamic behavior of the short emitted pulses.

Essentially high quantum yield metallic photocathodes such as tungsten needles or arrays of needles have been tested since the facility exists, but it is intended to study other cathodes before making the final selection.

As it is the facility is a laser triggered gun. Laser development is under way to produce stable trains of short light pulses at high modulation frequencies (S and X bands).

II High gradient studies

The lay out of the test facility is shown on Fig.1. Presently the klystron operates with a normal rectangular pulse, the maximum pulse length being 4.5 μs, but in the near future storage cavities will enable to compress the pulse down to 300 ns and raise the peak power up to 240 MW.

The linac part consists of a SLAC type gun which provides a nominal 2ns, 2A peak current (the pulse length can be increased to a few μs using a different grid pulser) and a LIL type 4 MeV, 3 GHz buncher. A 2 MW RF power is diverted from the klystron, through directional couplers, to feed this bunching section, while the remaining power can be used to feed accelerating sections under test. Since the buncher is a SW section with long filling time, the pulse compression scheme will not allow to use it during very high peak power tests.

Presently the available beam diagnostics only permit to measure the accelerated beam current as well as the field emitted current in the high gradient structure, the beam energy and the energy spread. It is intended to add an emittance measuring system.

The first accelerating section tested with the facility previously described is of the LIL type [8] but with a shorter length of 0.5 m corresponding to the last landing of the quasi constant LIL structure. The aim was to determine the operational gradient limit. However, up to now, the tests have been carried out at a gradient level of 30 MV/m only, due to a klystron failure (notice that LIL operates at 17 MV/m). The characteristics of the test structure are summurized hereafter :

v_g/c	$6.4\ 10^{-3}$	
r/Q	4700	Ω/m
Q	14100	

At 30 MeV/m the structure behaves quite well ; an RF power (25 MW, 4.5 μs) at 100 Hz repetition rate is injected in the structure without breakdown during time intervals greater than 1 hr, after a conditioning period of approximately 100 hrs. Under these conditions the maximum wall field is 60 MV/m and a dark current is observed with the time distribution of Fig.2. There is a peak intensity with a duration of approximately twice the filling time of the structure, followed by an equilibrium charge emission corresponding to a 40 μA current. This steady state current as well as the head peak current are plotted on Fig.3 as a function of the maximum surface field. The energy spectrum of the dark current extends from 2 to 18 MeV. The enhancement factor corresponding to the steady state field emission is obtained from the following formulae [9] :

$$\frac{d\,(log\ I/E^{2.5})}{d\,(1/E)} = \frac{-5.8\ 10^9\ \phi^{1.5}}{\beta}$$

where E is the maximum surface field and I the measured steady state dark current.

With $\phi = 4.65$ eV , one gets $\beta = 140.5$

The second accelerating structure which has been tested was designed and built within a CGR-MeV/LAL collaboration [10,11]. It is a 3 GHz, $4\pi/5$ backward TW mode, structure in which noses together with magnetic coupling slots in the irises permit to increase the shunt impedance with still high values for the group velocity (Fig.4).

This prototype is made of 29 cells (Fig.5) giving a total accelerating length of 1.27 metres. Low power level measurements have shown good agreement with theoretical expectations for the RF characteristics and emphasized the choice of the tuning method. At a 12.8 MW peak power level, with an accelerated beam, an energy gain of 19.1 MeV was measured corresponding to an effective shunt impedance of 77 MΩ/m , whereas the expected value from cold measurements is 84.3 MΩ/m (at $v_g/c = 2.17\ 10^{-2}$). Power test will be performed in the near future at the 37 MW level. Notice that the present structure is considered to become an interesting candidate for short RF pulse operation considering its high group velocity

III Photocathode studies

The original Lasertron programme led to specific fundamental and applied research in the field of high current, short pulse, photoemission and to the development of robust and efficient photocathodes [12,13].

A test station was built which now consists of :

- A picosecond Nd-YAG laser providing 15 ps short pulses in a 50 ns burst which repeats at 10 Hz (in most of our present work a single pulse is selected). The laser can be operated in the I.R., the green and the U.V.with an energy per burst (a burst comprises 7 micropulses) of 50, 20 and 8 mJ respectively.

- A small ultra high vacuum tank in which the distance between anode and cathode is adjustable down to a few mm and fitted with a 25 kV high voltage supply. One of the peculiarity of this tank is that the cathode support is especially designed to handle metallic needles and that the emitted current from the cathode is directly measurable in the cathode connection . This is particularly useful to determine field emission threshold with or without laser triggering.

- A big ultra high vacuum tank (fig. 6) presently fitted with a 150 kV d.c. power supply, which could handle an even higher voltage, and which has been designed to allow easy access to the anode region for special measuring equipments such as broadband coaxial faraday cup, transient radiation monitor, cerenkov monitor or resonant cavity. As it is the tank could either be operated as a laser-triggered gun or as a Lasertron as soon as cathode performances would permit it.

- A bench for preparing cesiated types photocathodes.

3.1 Photocathodes tests with the small tank.

Considering that cesiated photocathodes have poor lifetime when operated at high current it was decided to look at metallic cathodes. However, to increase the quantum efficiency it was suggested by H. Bergeret to use very sharp metallic needles, set the accelerating voltage just below the field emission threshold, and trigger the electron emission with a short pulse laser, preferentially operating in the U.V.. This kind of emission is often referred to as photo-field emission ,though in our experiments we have not yet discriminated between a photon effect and a macroscopic field effect from the laser (field emission triggered by laser).

The first cathode which has been experimented is a single tungsten needle (Fig. 7). Peak currents up to 2 A were obtained in a single pulse. The current was measured with a 1 GHz bandwidth oscilloscope and the observed current pulse length was of the order of 1 ns, thought the laser pulse was expected to be less than 60 ps.

The lack of ps measuring equipments does not yet permit to conclude about real values of peak current but set a lower limit on it.

The second photocathode was an array of silicon microemitters, obtained by lithography techniques, and coated with tungsten.

This array was made at BNL, and consists of 250 rows, 2.5 mm long, with a 10 μm separation between rows which thickness is of the order of 0.5 μm.

For this cathode the field emission threshold was higher as compare to a single W needle, and at the limit of the capability of the small tank. However with a small anode cathode distance, setting the voltage just below the d.c. field emission threshold, current pulses were observed under Green and U.V. laser illumination. Peak currents of the order of a few Amp were also measured with the same experimental conditions as previously mentioned.

Peak currents much higher have been reached by increasing the laser energy but led to a partial destruction of the cathode, probably due to thermal effects and breakdown (Fig. 8). As a matter of fact above a certain emitted current the pulse shows a long tail, characteristic of a thermal effect.

3.2 Photocathodes tests in the high voltage tank.

The previous SiW array was then put in the new HV tank and progressively conditionned under high d.c. voltages, up to 140 kV with cathode-anode distances of 2 to 3 cm.

In this tank the peak current is measured behind the anode with a broadband coaxial faraday cup, but still limited to a few GHz. Using a 7 GHz oscilloscope, current pulse rise time as low as 70 ps were observed at low emitted photo currents. Notice that since there is still no magnetic field to focus the emitted beam through the anode hole, only an unknown fraction of the total emitted current is captured on the coaxial pick up.

Qualitative behavior of this emitted current has been studied systematically and the preliminary results can be summarized as follow :

- The highest pulsed emitted current is observed for incident light angles close to 90°, as measured from the tank axis. The effect of polarized light will be studied in the future.

- Setting the d.c. accelerating voltage close to the field emission threshold, pulsed currents, triggered by the laser, show a linear variation with laser pulse intensity for U.V. light (Fig. 9) and a much faster variation for green light (Fig.10). The first case would be compatible with photoemission. For the second case a Fowler Nordheim plot has been tried successfully using the laser electric field, which could indicate a pulsed field emission triggered by the laser though the corresponding computed electric field is much below the applied d.c. accelerating field.

- The maximum current obtained under these conditions is essentially limited by breakdown. Generally when the accelerating voltage is increased the breakdown occurs at a lower laser intensity. It is also observed that the current pulse start lengthening prior to the breakdown. After a certain amount of breakdown the cathode, observed with an electron microscope, was badly damaged and needed to be replaced.

IV Conclusions

Metallic photocathodes have shown high quantum yield in the short pulse regime when used as sharp needles. However, the step which consists of increasing the current by using an array of needles is still not satisfactory in many ways.

A particular attention need to be given to thermal effects and breakdown. In this respect efforts will be made towards pure metallic arrays of needles.

Clearly, at the moment the short pulse currents are two low to be useful for a Lasertron. In addition more work need to be done to characterize the exact pulse current and pulse length beyond the anode. Hence it is envisaged to use a solenoidal field to focus the beam, and to replace the coaxial pick up with a transient radiation monitor (or a low energy cerenkov monitor) followed with a streak camera.

References

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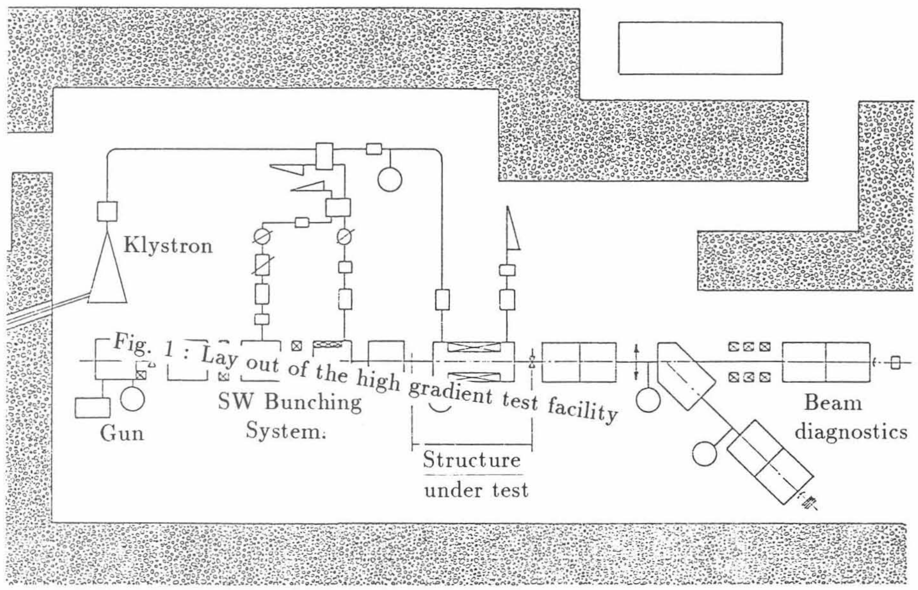


Fig. 1 : Lay out of the high gradient test facility

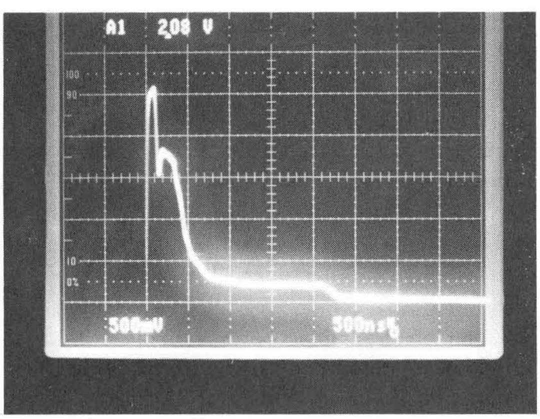
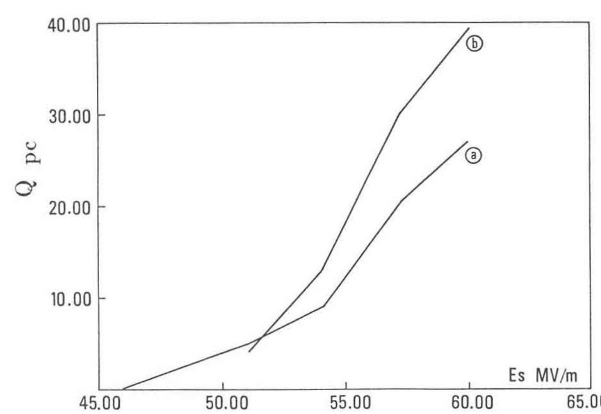


Fig. 2 : Time distribution of dark current



b) Charge in 0.5 μs head pulse

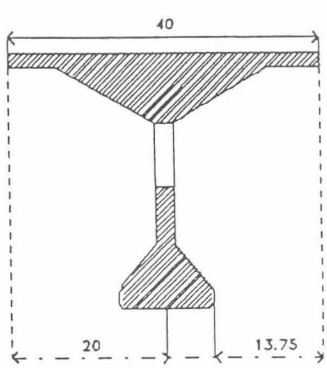


Fig. 4 : $4\pi/5$ H-coupled cell design

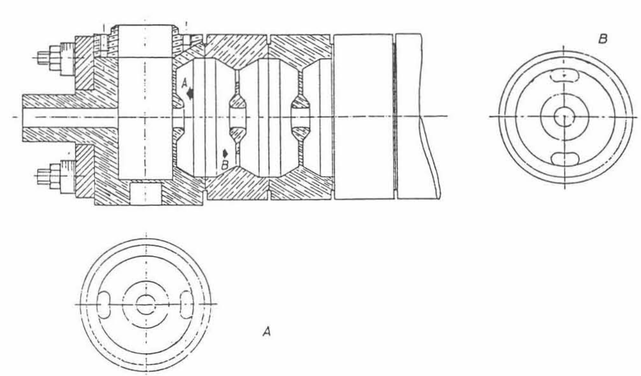


Fig. 5 : $4\pi/5$ backward TW unit

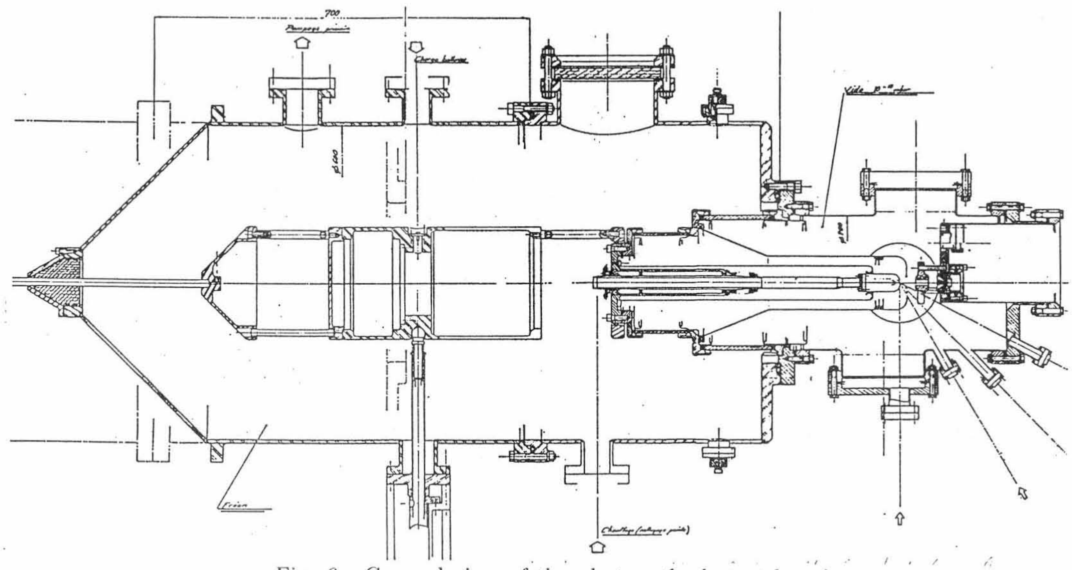


Fig. 6 : General view of the photocathode test bench

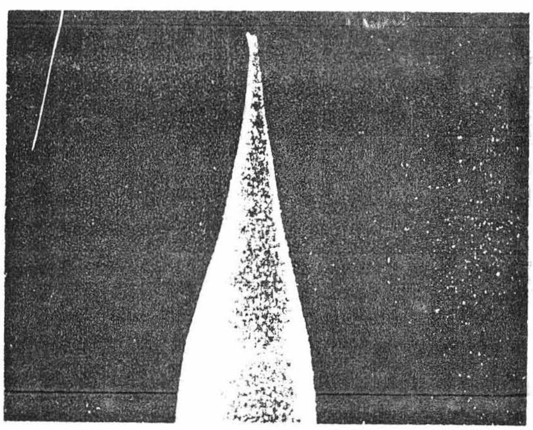


Fig. 7 : Single microscopic W needle (enlarged by a factor ≃ 400)

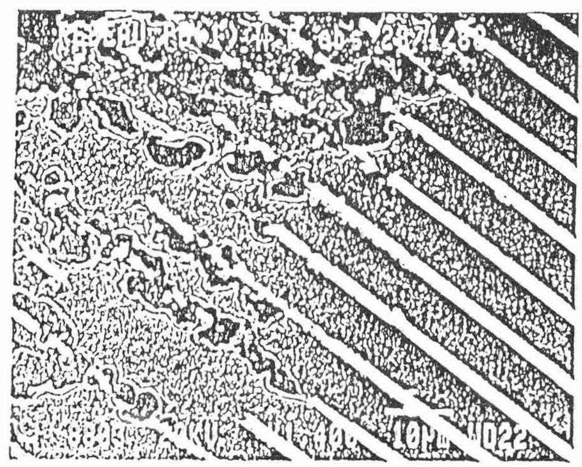


Fig. 8 : View of a locally destructed region of the SiW photocathode

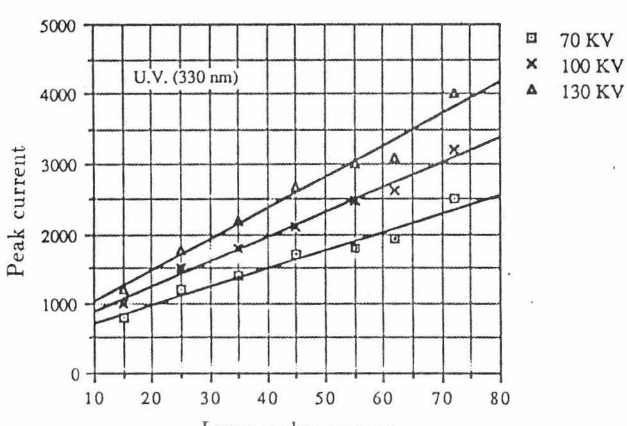


Fig. 9 : Peak current versus laser energy for U.V. light

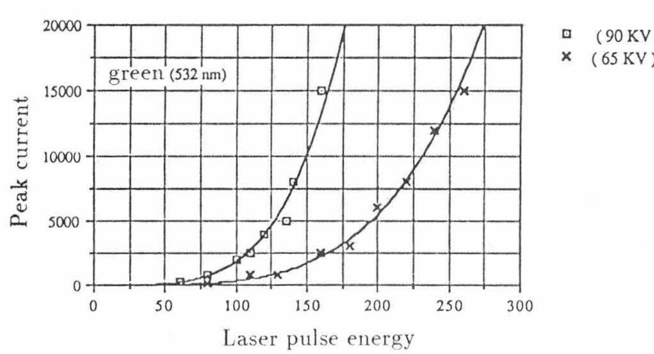


Fig. 10 : Peak current versus laser energy for green light