High Performances from a GaAs Photoemitter

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Abstract

This paper aims at collecting the experimental results we have obtained about a GaAs photocathode, activated in negative affinity condition by depositing a thin layer of caesium and oxygen at its surface.

1. CONTINUOUS WORKING OPERATING REGIME

The experimental apparatus consists of a cathode-anode system at which one can apply a prefixed voltage (V_{ac}). Laser excitation by a continuous Ar laser (λ=500 nm) produces an electron beam, the current of which (I_{ac}) is collected at the anode and measured through a 1 kΩ resistor. A dispencer and a leak-valve, placed close to the cathode, provide cesium and oxygen supply, respectively. A more detailed description of the apparatus can be found in Ref. [1]. After usage, cesium-oxygen treatment can be repeated for re-activating the source [2]; a regeneration of the GaAs sample, heating up to 630 °C, is requested after some activations [1]. Either activations or measurements with the cathode working are carried out under ultra high vacuum.

Fig.1 illustrates the relationship of the current I_{ac} as a function of V_{ac}, at fixed values for the laser power P. One can observe that, at P=63 mW, the maximum current is 1.8 mA, corresponding to a quantum yield Y=7.4%. At lower current (100 μA), Y attains its maximum at Y=10%.

As the photocathode works, surface deposition of some damaging compounds causes current decay; we therefore measured the lifetime τ of the source (meant as the e-folding value of the initial current) for different current values, as reported in Tab.1. The bottom row is referenced to the measurement carried out by a Ti:Al_2O_3 laser, tuned just over the GaAs band-gap, at 800 nm.

Table 1
Lifetime as a function of emitted current

Iac(0) [μA]	τ [h]	Laser
80	580	Ar
805	213	Ar
1800	0.5	Ar
400	140	Ti:Al_2O_3

Lifetimes are very long and show a sensitive decreasing when increasing the current. It can be interpreted owing to anode desorbtion, at the highest current, which enhances the pressure in the chamber, and consequently poisons the cathode [1]. We believe that the good performances of our photocathode are mainly due to the low-vacuum working condition (10^{-11} ÷ 10^{-10} mbar) and to the ohmic heating of the GaAs crystal [1,2].

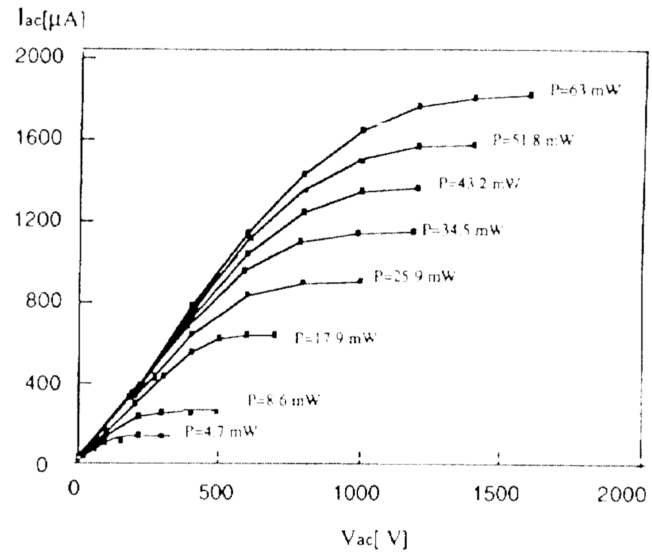

Figure 1. Emitted current I_{ac} as a function of anode-cathode voltage V_{ac}, for differrent values of the laser power P.

2. PULSED OPERATING REGIME

With the same appararus, we extracted electron bunches [3], "bombarding" the cathode by light pulses 10 ns long, produced by a 532 nm, frequency doubled Nd:YAG laser. Electron bunches are collected at the anode, whereas their charge is released and measured over a 1MΩ, 260 pF RC circuit. Fig.2 shows bunch charge as a function of anode-cathode voltage V_{ac}. In this case the quantum yield is very low (~10^{-3}%) inasmuch space-charge effect limits the emission capability of the source. Thus, increasing the current, an even greater value for the bunch-charge is attained. We limited V_{ac} at 12 kV because some effluvia began to appear; at this voltage a charge of 18 nC/bunch is recorded. Even though the repetition rate of the laser was 10 Hz, a 75 hrs lifetime has been measured [3]. The good performances of the photocathode allow considerable electron bunch extraction even at relatively small voltage (6 kV/cm). In this way all problems connected at operating at high voltage are bypassed.

Due to the high charge production per bunch the source can be employed as an electron injector for a free electron laser and colliding beams.

These measurements and those of the previous section have been repeated many times, demonstrating a reliable ripetitivity of the method.

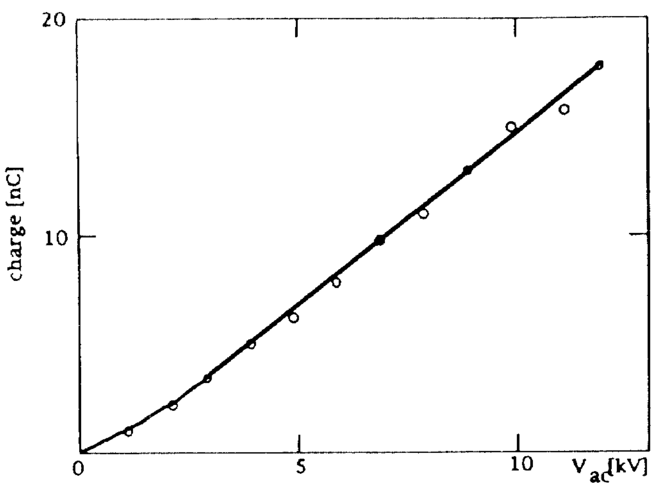

Figure 2. Average charge per electron bunch as a function of anode-cathode voltage V_{ac}, when illuminated by Nd:YAG laser.

3. LASER MODES AND BEAM ENERGY SPREAD

On the basis of experimental evidences, U.Kolac *et al.* have conjectured the possibility that laser modes might influence the energy spread of emitted electron beam from a GaAs source [4]. We have directly measured and compared the values of the energy spread for a single-mode $Ti:Al_2O_3$ and a multi-mode He-Ne lasers [5].

An improved version of the previously described apparatus has been built. The generated electron beam is accelerated by means of a Pierce electrode; after that it enters an accelerating structure, the electrodes of which can be set at any voltage (0÷900 eV). A drift tube and a collector energy analyser then follow this section. The energy analyser employs the retarding potential technique; the resolution of this device is always less than 8 meV. A full description is in Ref.[6].

The difference in the longitudinal energy spread between the single-mode and the multi-mode laser for producing the same current are clearly displayed in Fig.3. As the former has a constant value for the power, mode interference in the latter case, leads to very fast power fluctuations, which changes the character of electron relaxation inside the beam [5] and then affects the longitudinal energy spread. This effect starts growing when the cathode is in the limited-emission regime, where the electron current can follow laser power fluctuations. In this condition the energy spread of the photocathode is even worse than that of a thermocathode. Indeed, in space-charge regime any power modulation is offset by the electron cloud in front of the cathode. In this region both curves of Fig.3 therefore overlap each others.

On using a single-mode laser we measured 85 meV longitudinal energy spread (FWHM), at the cathode, for 100 μA current We repeated the measurement at 100 K temperature, recording 54 meV.

Finally we have demonstrated that the use of a single-mode laser allows minimal values of the longitudinal energy spread, opening good opportunities to use this source directly in many research fields (solid state, electron cooling,...).

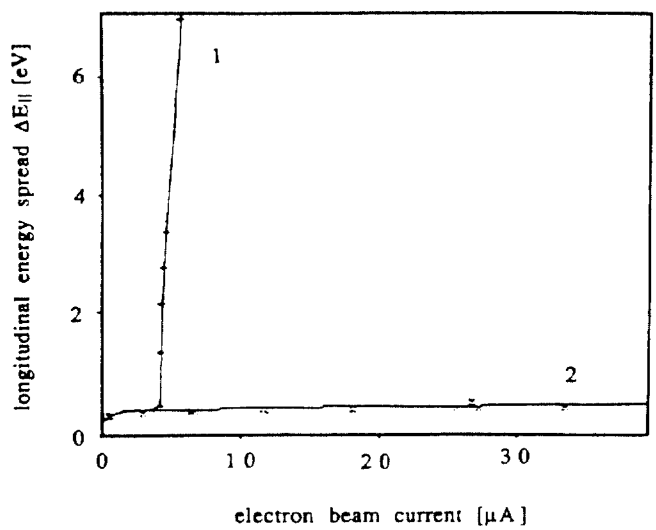

Figure 3. Influence of the laser modes on the energy spread for: 1) multi-mode laser, 2) single-mode laser.

4. ELECTRON BEAM AND PLASMA PARAMETER

In the last section we have shown how to produce a relatively intense low-energy-spread electron beam. Now it arises the problem of accelerating electron beam up to the requested energy for each specific application, maintaining the energy spread as low as possible. We investigate the possibility of accelerating electrons in a "slow" way. It is well known that a strong magnetic field separates the longitudinal freedom degrees of a beam from the transverse ones [6]. In this case a pure longitudinal relaxation occurs [6]; we showed that an adequately slow (i.e. adiabatic) acceleration allows minimal energy spread after acceleration, by damping the relaxation process [7]. The condition for this acceleration is that the equilibrium between potential energy and the kinetic one is always fulfilled so that the beam relaxes during acceleration.

Therefore the coupling of a single-mode laser and an adiabatic structure has achieved to the best results.

The ratio between the potential energy and kinetic (thermal) one, for a quite general system, is defined as plasma parameter Γ [8]. Many computer simulations (see for instance Ref. [9,10]) regard this parameter as an ordering-estimate for the system. When Γ exceeds one, strong correlations between ions occur and a liquid behaviour is expected at Γ=3. Indeed, at Γ=170 a crystaline structure should appear [9,10] (Wigner's crystal). An usual accelerating device for electrons has always $\Gamma_e \ll 1$. We simultaneously measured the current density and the energy spread, then we calculated $\Gamma_{e||}$; these values are reported in Fig.4. We demonstrated that the adiabatic acceleration can exceed the limit $\Gamma_{e||}=1$ over a wide current density range ($1.0 \div 6.4$ mA/cm^2).This is the first experimental observation of an electron beam with a plasma parameter greater than one ($\Gamma_{e||max}=1.4$, see Fig.4) [7]. A comparison with an usual acceleration is also shown in Fig.4.

An electron beam, having the characteristic $\Gamma_{e||}>1$ would be of excellent usage in electron cooling of ion beams, by enhancing its efficiency. If Γ_i denotes the plasma parameter for an ion beam, a high value for Γ_i is expected when the ultracold electron beam is applied to electron cooling ($\Gamma_i=Z^2\Gamma_e$, Z is ion's charge [11]). It appears evident that even more ordered state for the ion beam seems to be possible, opening the possibility to reach beam crystallisation.

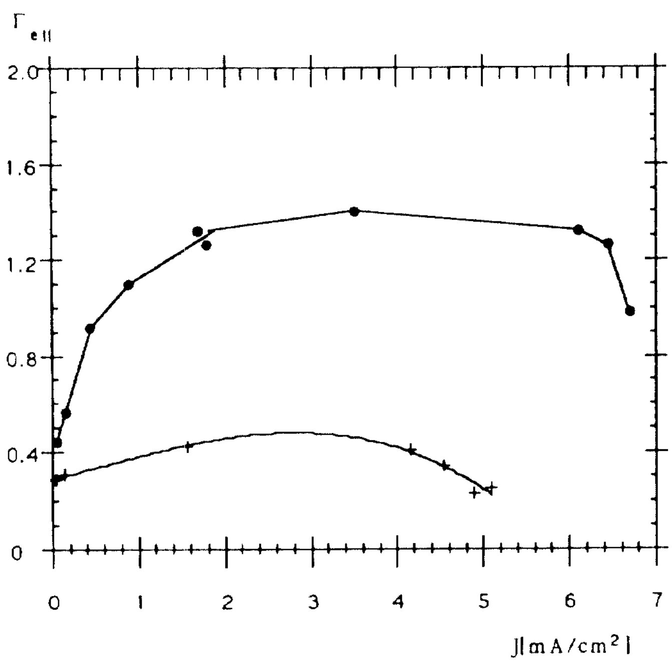

Figure 4. Relationship between the electron plasma parameter $\Gamma_{e||}$ and the beam current density j for adiabatic (•) and usual fast acceleration (+).

5. REFERENCES

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