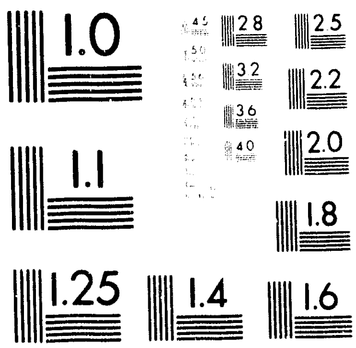
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MEASUREMENT OF CHARGE LIMIT IN A STRAINED LATTICE GaAs PHOTOCATHODE*

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ABSTRACT

The SLAC Linear Collider (SLC) Polarized Electron Source (PES) photocathodes have shown a charge saturation when illuminated with a high intensity laser pulse.[1] This charge limit in the cesium-activated GaAs crystal seems to be strongly dependent on its surface condition and on the incident light wavelength. Charge limit studies with highly polarized strained lattice GaAs materials are presented.

1. INTRODUCTION

The SLC PES uses GaAs photocathodes for the production of high intensity polarized electron beams for use in high energy physics experiments.[2] Some III-V semiconductors such as GaAs have a large direct bandgap which gives them good optical absorption coefficient and low thermionic emission.[3] The ability of p-type semiconductors to achieve negative electron affinity (NEA) together with an essentially empty conduction band give photoexcited electrons a large escape probability.[3] A high voltage of V=120 kV is required to produce space charge limited beams of ~8 Amps required for collisions. The space charge limit (also known as Child's Law[4]) scales as $pV^{3/2}$, where p is the perveance of the gun. This perveance depends on the geometry of the electrodes and on the active photocathode area. The charge limit effect discussed below occurs when the maximum photocharge produced is below this space charge limit.

The SLC high energy physics program requires beams with very high longitudinal polarization. Since the GaAs and AlGaAs photocathodes produce electron beams with only 40-50% polarization when illuminated by circularly polarized light, SLC is using a strained lattice GaAs photocathode which produces an electron beam with ~80% polarization. Similar more highly strained photocathodes have been shown to produce greater than 90% polarization.[5] The current program at SLC and the Next Linear Collider project require high intensity, high polarization photocathodes. Thorough understanding of the charge limit will help in the design of better high intensity photocathodes.

2. EXPERIMENTAL SETUP

The Gun Test Laboratory used for these studies is a replica of the first few meters of the SLC injector. The facility consists of an electrostatic electron gun with a loadlock system for easy cathode exchange, a Nd:YAG-pumped pulsed Ti:Sapphire tunable laser, and an electron beamline with beam monitoring capabilities.

The gun consists of a pair of cylindrical Pierce electrodes with a 14 mm diameter semiconductor photocathode.[6] The photocathode is operated in reflection mode, photoelectrons are emitted from the illuminated surface. The gun ultra high vacuum (UHV) has a total pressure of $\sim 1 \times 10^{11}$ Torr and is monitored with a Residual Gas Analizer. Photocathodes can be retrieved through the back of the gun into a loadlock system.[7] This loadlock system permits exchange of photocathodes in UHV as well as cathode heat-cleaning and surface activation into NEA with a $Cs\text{-}NF_3$ monolayer. A channel cesiator and a NF_3 leak valve in front of the electrodes are used to restore NEA after it has deteriorated below useful levels. An ammeter in series with the gun power supply measures the photocurrent.

A series of magnets transport the electron bunch from the gun into a charge integrating Faraday cup (FC). A gap monitor one meter from the gun measures the electron bunch temporal profile. The charge transmission between the gun and the FC for an optimized beamline is greater than 95%.

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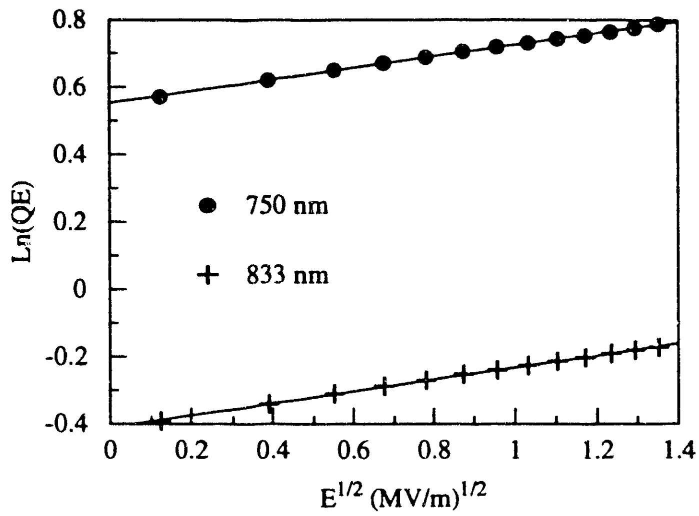

Figure 1. QE measured at 750 nm and 833 nm as a function of the applied electic field. The QE appears to follow the Schottky effect.

The laser system consists of a high intensity Ti:sapphire laser pumped by a Nd:YAG laser.[8,9] The laser wavelength is tunable between 750 nm and 870 nm. A pulse chopper Pockels cell system and an intensity control Pockels cell system produce a Gaussian pulse 2 ns full width at half-maximum (FWHM) and a near-Gaussian transverse profile. The Ti:sapphire laser spot size is always adjusted to fully illuminatethe photocathode in the experiments below. Low power lasers used for quantum efficiency (QE) measurements include a HeNe laser at 633 nm and various cw diode lasers with wavlengths of 751, 833 and 850 nm.[10]

The two photocathodes discussed in this paper are a strained lattice GaAs material with a 0.3 μm active layer and doping of 5×10^{18} Be atoms/cm^3 and a bulk GaAs material with doping of 2×10^{19} Be atoms/cm^3.

3. EXPERIMENTAL RESULTS

The photoemission response of a photocathode after activation depends mainly on the surface condition (level of NEA), the excitation light wavelength and the applied electric field. The applied electric field E lowers the surface potential barrier by an amount proportional to $\sqrt{E}$, which is known as the Schottky effect.[11] The surface escape probability of the photoexcited electrons is then proportional to $e^{\beta\sqrt{E}}$. The QE for the strained layer cathode measured as a function of E at two wavelengths is shown in Fig. 1. As the QE of cathodes increases with good surface conditions (large NEA), the dependence on the applied electric field becomes less pronounced. All QE measurements in this paper were done with the cathode biased at V=-120 kV.

The photocurrent saturates at high laser power. At a wavelength of 532 nm the saturated charge is 13.3×10^{10} e^- per laser pulse in bulk GaAs at 120 kV. Fig. 2 shows a plot of saturated charge versus voltage. The data show a $V^{3/2}$ dependence as expected for a space charge limited current. SLC benefits from running the photocathode in saturation because then the photoemission is less sensitive to laser jitter.

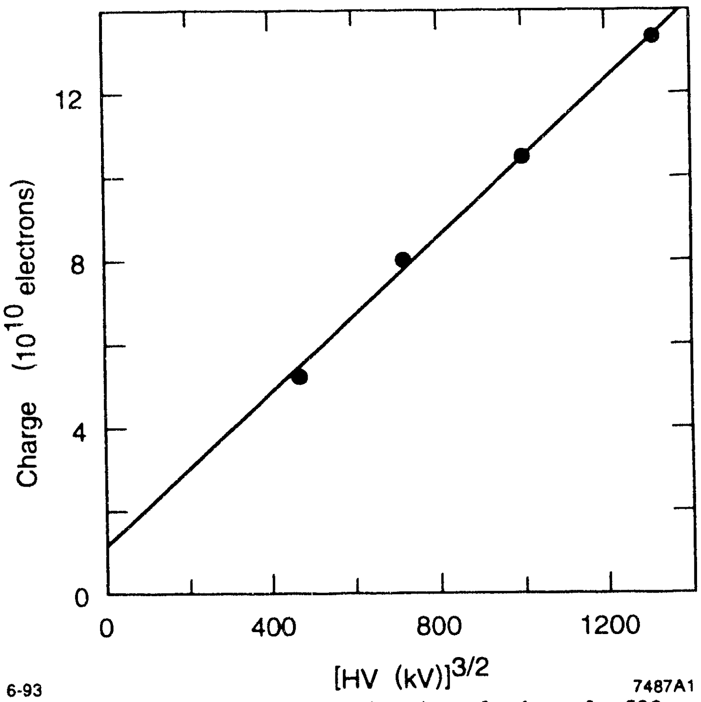

Figure 2. Saturated current as a function of voltage for 532 nm laser illumination. The saturated current appears to scale as $V^{3/2}$ as expected for space charge limit.

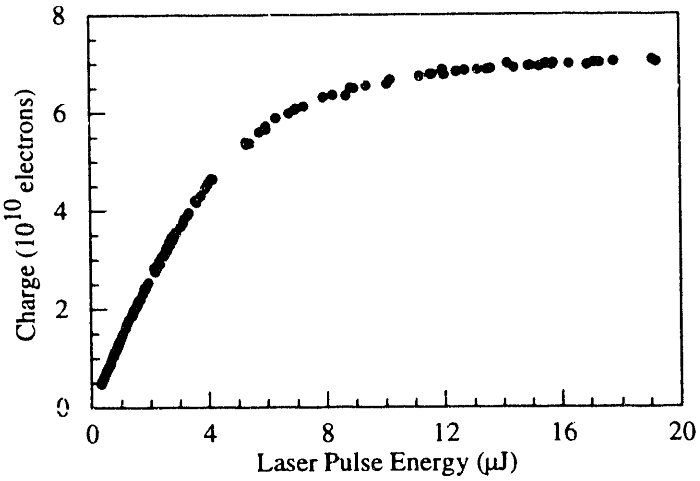

Figure 3. Typical photoemitted charge in the charge limit regime as a function of Ti:sapphire (850 nm) laser pulse energy. The photocathode QE was 1.51% and 0.57% at 750 nm and 833 nm, respectively. The cathode voltage was V = -120 kV.

To produce a highly polarized electron beam, the excitation wavelength must be near the semiconductor's bandgap threshold, i.e. above 700 nm for GaAs. We found that operating at these wavelengths, the maximum charge which can be extracted is less than the space charge limit when the QE drops below a certain level. A typical saturation curve for the strained photocathode in which the QE is 1.51% with 750 nm light (0.57% at 833 nm) is shown in Fig. 3. The saturated charge in the charge limit region seems to depend linearly on the QE as shown in Fig. 4.

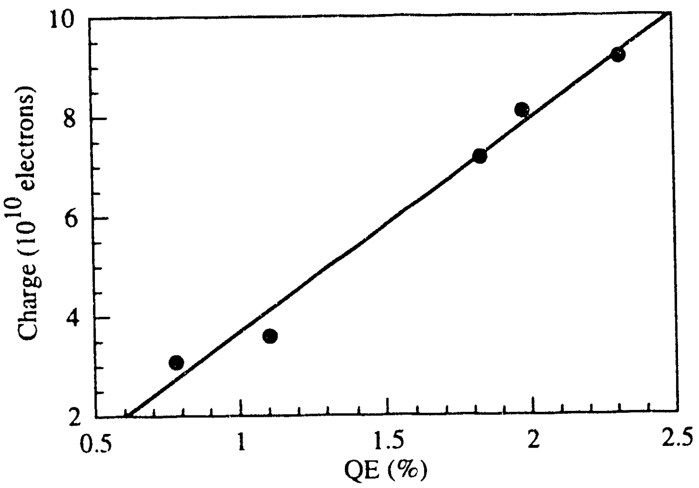

Figure 4. Saturated current in the charge limit regime as a function of surface condition (QE). The cathode voltage was V = -120 kV.

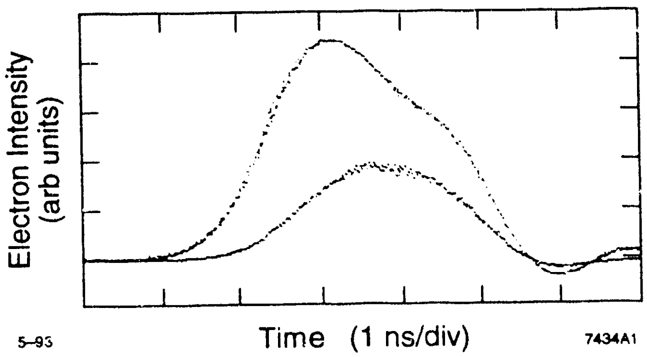

Figure 5. Electron bunch shapes for incident laser (850 nm) pulse energies of 30 mJ (top trace) and 3 mJ (lower trace). The profiles show charge limit and linear response behaviors, respectively.

The effect of the charge limit on the electron bunch can be seen in the time resolved electron intensity measurement with the gap monitor. Two temporal profiles of the electron bunch for the strained photocathode with low and high laser intensities, corresponding to non-charge-limited and charge-limited cases, respectively, are shown in Fig. 5. At low laser intensities, the electron bunch shape is symmetric and closely resembles the shape of the laser pulse, indicating that the photocathode response to the light intensity is approximately linear. At the high laser intensity, when the charge limit is reached, the electron bunch shape becomes asymmetric and peaks at an earlier time than the light pulse. This behavior differs from the space charge limit behavior in which the bunch shape has a symmetric flat top in saturation.

As shown for the strained photocathode in Fig. 6, the maximum charge appears to have a linear dependence on V. These data point to a stronger dependence of the maximum charge on the applied electric field than can be accounted for by the increase in QE due to the Schottky effect.

Even though the charge limit relaxation time has not been studied carefully, several important observations have been made. The operation of the source at SLC requires two electron bunches separated in time by 60 ns. The strained photocathode doped with 5×10^{18} Be atoms/cm^3 showed 10-20% less charge in bunch 2 due to the presence of bunch 1. Earlier experience with a bulk GaAs photocathode with similar doping concentration showed a bunch to bunch effect of similar magnitude. However, for the higher-doped bulk-GaAs photocathode mentioned earlier in this paper, no bunch to bunch effect was

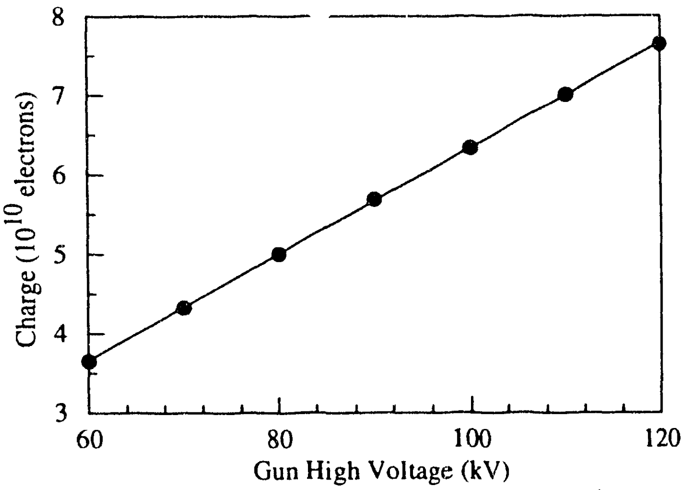

Figure 6. Saturated current in the charge limit regime as a function of voltage at 850 nm. The QE was 1.29% at 750 nm.

observed. More rigorous testing is required to properly characterize the effect of doping concentration on the charge limit relaxation time.

4. CONCLUSIONS

This paper reports the results of several measurements of charge limit as a function of QE and voltage for a 0.3 μm strained lattice GaAs photocathode. The charge limit was observed to depend on the photocathode surface condition, the incident laser wavelength and the applied voltage. A natural extension of this work would be to measure charge limit as a function of active layer thickness, dopant type and concentration, and temperature. Detailed studies comparing dissimilar cathodes are somewhat hampered by the lack of a practical method to experimentally quantify the surface conditions in our system. Other III-V semiconductors have been proposed as candidates for high polarization strained lattice photocathodes which may have significantly higher charge limit.[12] A Mott polarimeter to be installed in the beamline this summer will provide measurements on the electron beam polarization as a function of various photocathode surface conditions.

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