Electron beam generation by electron multiplication

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We have demonstrated that intense pulsed electron beams can be created by multiplication of lower current electron streams impinging on a high electron yield target. A 17 A electron beam of 1 μs pulse width was generated from a 2.5 A beam bombarding an activated Ag-Mg target 2.5 cm in diameter.

We have demonstrated a new approach for the generation of broad-area intense electron beams based on the multiplication of electron streams achieved by bombarding high-yield materials. This well known phenomenon has been employed for decades in photomultiplier detectors to amplify currents in the submilliamp range,[1] but to our knowledge has never been used for the generation of intense electron beams. We report the generation of broad-area electron beam pulses of 1 μs duration with current densities up to 3.4 A/cm^2 by single-stage multiplication of a 0.5 A/cm^2 electron stream. The scheme has the potential of generating intense electron beams whose current and pulse width are tailored by controlling a low current density beam.

Ion and photon fluxes have been previously used to cause intense electron emission from cold cathodes. The emission of electrons from cathode materials following the bombardment by energetic ions has been widely used in the generation of broad-area electron beams.[2-7] While many cathode materials exist which present high electron yields following the bombardment by ions,[8,9] ion bombardment electron guns have limitations for the generation of very high current density beams. For a given electron yield, the electron beam current density is limited by the bombarding ion flux, which is itself limited by the large positive space charge. Also, ion bombardment induced sputtering of the cathode material is an undesirable effect that is present and limits the electron gun lifetime. Recently, very large electron beam current densities have been achieved using photocathodes.[10,11] The photoemission scheme has the advantages that photons do not present space-charge limitations or cause sputtering. An additional advantage of photocathodes is the very small energy spread of the emitted beam produced by monochromatic irradiation. However, the laser required as a photon source increases the size and complexity of the cathode, and also limits its scaling to very broad areas.

In the experiments reported herein, an electron beam was generated by electron bombardment induced emission of an activated Ag-Mg target 2.5 cm in diameter. In this scheme the electrons emitted by a low current density primary electron source impinge on a high electron yield target at an energy close to that required for maximum emission of secondary electrons. The secondary electrons are subsequently accelerated in the opposite direction to form a higher current density beam. Electrons cause negligible sputtering and create a space charge which is two orders of magnitude lower than that corresponding to an ion beam of the same flux and energy. The experiments reported in this letter show that some of the same materials and surface activation procedures developed for electron multiplication of the microamp level in photomultiplier tubes allow for efficient electron multiplication at current densities many orders of magnitude larger. Consequently, the scheme reported herein has the potential of generating very high current density electron beams.

The setup used to demonstrate this electron beam generation scheme is represented in Fig. 1. The primary, or seed, electron beam pulse is generated from a 2.5-cm-diam thermionic dispenser cathode, by pulsing an accelerating grid to positive potential with respect to the cathode and floating them negatively with respect to a grounded grid. The beam propagates to another grounded grid placed in close proximity with the target. The target is negatively biased with respect to ground to retard the electrons from the seed beam, such that they will bombard its surface with an energy close to that necessary for maximum electron yield (about 1 keV for Ag-Mg targets). Electron beam multiplication has been achieved using an activated Ag (98.3%)-Mg (1.7%) polycrystalline alloy target. The target and its corresponding grounded grid are positioned forming an angle with respect to the axis of the primary beam, either 11° or 30° in the experiments reported herein, to allow extraction of the secondary beam as it will be required in practical applications. An additional benefit of this configuration is that the electron yield is slightly increased with respect to the normal incidence value. The entire setup is enclosed in a stainless-steel chamber 20 cm in diameter that is evacuated to a pressure of 1×10^{-7} Torr using a turbomolecular pump. In the electron

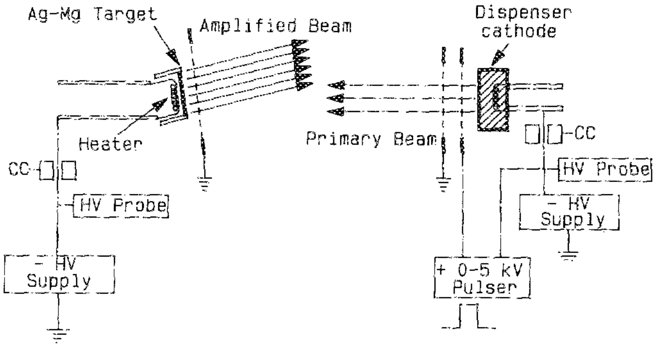

FIG. 1. Schematic representation of electron multiplication setup. Current coils are identified by CC. The vacuum chamber is not shown.

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multiplication experiments the chamber is filled with 5×10^{-4} Torr of argon to provide quasineutralization of the electron streams and thereby overcome the current limitations set by the propagation of unneutralized electron beams of less than 10 keV in an equipotential region.[12]

The Ag-Mg target surface was activated to obtain large electron yields following a procedure developed to activate dynodes of photomultiplier tubes made of the same material.[13] The procedure consists in diffusing Mg to the surface by heating the target and achieving oxidation in a CO_2 atmosphere to form a magnesium oxide layer. Failure to activate the target surface was observed to yield multiplication factors of less than 2. After the target temperature was increased to 750 °C and exposed for 2 min to an atmosphere of 400 mTorr of CO_2, yields of five were consistently observed and yields up to seven have been occasionally measured. Higher yields might result from the optimization of the thickness of the oxide layer; a systematic optimization of the activation procedure has not yet been completed.

In Fig. 2 the oscilloscope traces show the effect of electron multiplication. The top trace corresponds to the current pulse collected at the grounded target when bombarded by an 8 keV primary beam impinging at at angle of 30°. In this situation the secondary electrons rapidly form a space charge that inhibits significant electron emission and consequently the target current can be considered a good approximation of the primary beam current impinging on the target if backscattering is neglected.[14] This assumption was verified by applying a 50 V positive bias to the target, in which case the current changed by less than 15%. The bottom trace is the measured target current when all conditions are maintained equal, but the target is biased to − 5 kV. In this situation the primary electrons arrive at the target surface with an energy of 3 keV and the secondary electrons are accelerated to form a 5 keV beam. The bottom trace is the sum of the primary beam current arriving to the target and that of the emitted secondary electron current. Figure 2 shows that for a primary beam current of 2 A a secondary beam current of 11 A was emitted, corresponding to a multiplication factor of 5.5. The shape of the multiplied electron pulse is observed to follow that of the 1 μs primary beam. Impinging on the target with a current of 2.5 A (0.5 A/cm^2) produced 17 A (3.4 A/cm^2) of emitted current when the primary beam had an energy of 8 keV and the target was floated to − 4 kV.

Figures 3(a) and 3(b) show the electron multiplication factors measured as a function of the energy of the primary electrons, for primary beam current densities of 0.3 and 0.6 A/cm^2, respectively, impinging at angle of 11°. In both cases the electron yield is observed to increase from approximately one for a 9 keV primary electron energy to nearly five for a primary electron energy of about 3 keV. No degradation of the yields was observed to occur after hours of bombardment with μs-long electron beam pulses at a frequency of 1 Hz. Increasing the magnitude of the negative voltage bias of the target such that the primary electrons would arrive at the target surface with an energy of less than the smallest value shown in Fig. 3 would probably result in further increase in the yield; however, this was observed to distort the current pulse due to the onset of oscillations.

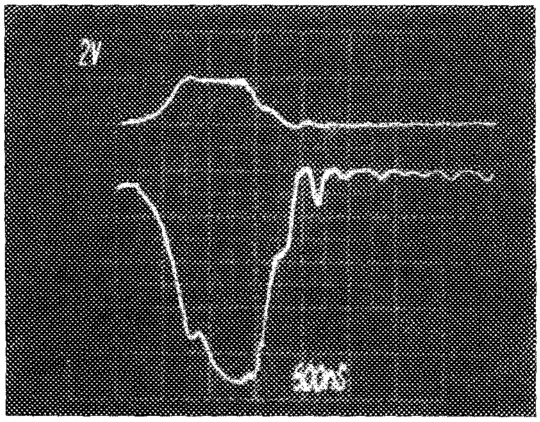

FIG. 2. Current flowing to the Ag-Mg target bombarded with an 8 keV electron beam when the target is grounded (upper trace, 2 A/div) and when it is biased to − 5 kV (lower trace, 2 A/div). The lower pulse represents the sum of the primary beam current collected (positive current) and the emited current (negative current). The background pressure of argon is 5×10^{-4} Torr. The angle between the normal to the target and the axis of the primary beam is 30°, and the distance between grounded grids is 8 cm.

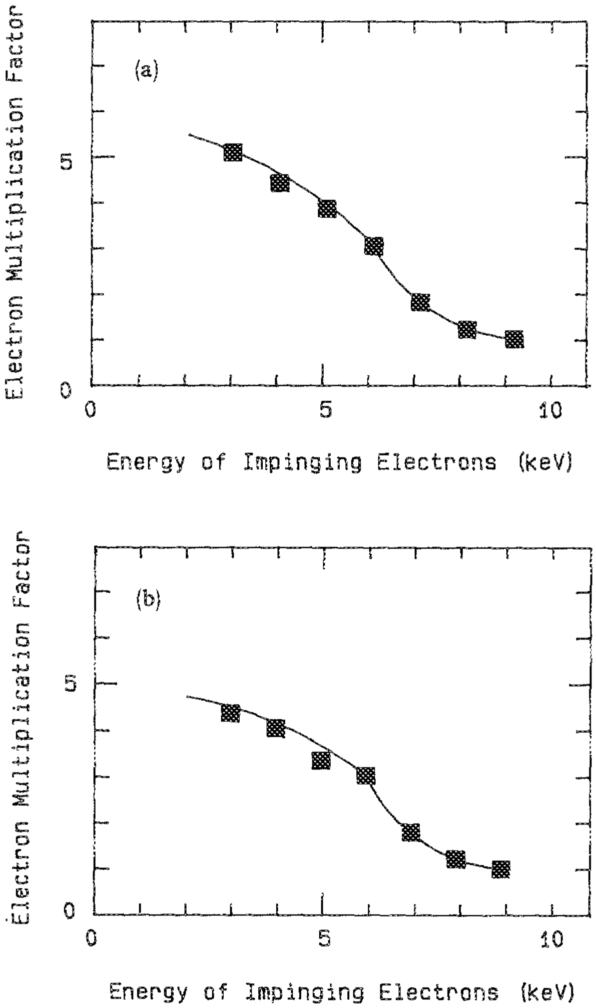

FIG. 3. Electron multiplication factors as a function of impinging electron energy for an input current of (a) 1.5 and (b) 3.0 A. The angle between the normal to the target surface and the primary beam is 11°, and the distance between grounded grids is 14 cm.

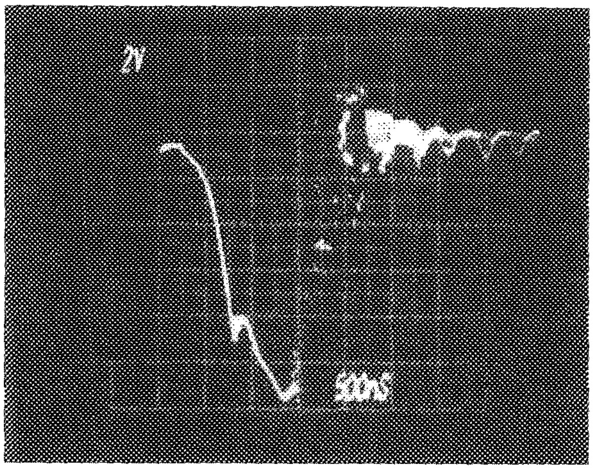

FIG. 4. Target current measured for the same primary beam conditions of Fig. 2 but biasing the target to − 5.2 kV. Oscillations are observed to occur at the end of the emitted current pulse.

Figure 4 illustrates the onset of the oscillation for the same primary beam conditions of Fig. 2, occurring when the magnitude of the bias is increased by 200 V to − 5.2 kV. The emitted target current increases to 13 A, corresponding to an electron multiplication factor of 6.5, before the current pulse is disrupted by oscillations. If the observed instabilities are avoided, it should be possible to achieve significantly larger electron beam currents than those reported herein. The nature of the observed instabilities has not yet been studied, but they could be due to electron-ion oscillations known to occur in the propagation of quasi-neutralized electron beam.[15-17] If this is the cause, the onset of the instability could be shifted to higher current values by increasing the electron beam acceleration potential,[15-17] which in the current experiment was limited to less than 10 kV.

In summary, we have achieved single-stage electron multiplication by a factor > 5 for 1 μs pulses at current densities more than three orders of magnitude larger than those produced in photomultiplier tubes. Electron multiplication in high-yield targets has the potential of producing intense electron beams.

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