CRITICAL (BURST) ELECTRON EMISSION FROM
DIELECTRICS, INDUCED BY INJECTION OF A
DENSE ELECTRON BEAM

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A dense pulsed electron beam and nanosecond pulse length has been used to inject negative electric charge into various dielectric materials (single crystals, glasses, composites, plastics) for initiation of electron field emission from the dielectric into a vacuum. It has been shown that upon reaching a critical electric field in the bulk and at the dielectric surface there is intense critical electron emission. The local current density from the emission centers reaches a record value (for dielectrics) of the order of 10^8 A/cm². The emission occurs in the form of a single gigantic pulse. The measured amplitude of the emission current averaged over the emitting surface is the same order of magnitude as the injected electron current: 10-1000 A. The emission current pulse lags behind the current pulse of the primary electron beam injected into the sample. The delay time is in the range 1-20 nsec and decreases with increasing current density of the injected beam. Direct experimental evidence is found for intense generation of carriers (band or quasifree electrons) in the near-surface layer of the dielectric in a strong electric field due to the Frenkel-Poole effect and collisional ionization of traps, usually various donor levels. This process greatly strengthens the field emission from the dielectric. It has been shown experimentally that the emission is nonuniform and is accompanied by "point bursts" at the surface of the dielectric and ionized plasma spikes in the vacuum interval. These spikes are the main reason that the transition of the field emission into "bursts" is critical, similar to the current which has been previously observed in metals and semiconductors. However there are a number of substantial differences. For example the critical field emission current density needed for the transition into "bursts" is three orders of magnitude less than for metals. If we provide sufficient electron current at the surface or from the bulk of the dielectric to the emission centers, then the critical emission is always accompanied by a vacuum discharge between the surface of the dielectric and a metallic collector. A detailed computer model of the processes in the dielectric during injection of a high-density electron beam has been developed which allows one to understand the complex physical pattern of the phenomenon.

INTRODUCTION

Electron emission from dielectrics induced by injection of an electron beam into a sample has been studied experimentally for sixty years. However these studies have not been systematic, but episodic. Several forms of pulsed emission have been seen. The best known are the observations of Malter (1936-1937) and Dow, Nablo, and Watson (1967-1968). Malter studied secondary electron emission of aluminum oxide (Al₂O₃) thin films coated with cesium oxide (Cs₂O) on an aluminum substrate [1]. The measured secondary emission coefficient reached several hundreds or even thousands. This "Malter emission" has been observed for thin films of many other dielectrics [2, 3].

Pulsed electron emission of bulk ("thick") dielectrics induced by injection of a low-intensity electron beam which is fully absorbed by the sample was first observed by Dow, Nablo, and Watson [4, 5]. They observed that upon reaching a certain threshold the value of the density of the charge from the injected beam was absorbed by the dielectric, the field outside the sample fell sharply, and simultaneously there was a "burst" of electron emission. This emission was later called DNW emission from the names of the authors.
Fig. 1. Experimental scheme of Dow, Nablo, and Watson [4, 5] for measuring the emission of dielectrics under the action of a low-density electron beam: 1) sample; 2) electron beam; 3) probing electron beam; 4) horizontal deflecting plates; 5) fluorescent screen; 6) metal stage; 7) current collector; 8) photographic equipment.

Fig. 2. Oscillograms of pulses of the electric field strength at the surface of the dielectric (E) and the emission current (I) during a pulse of length τ.

Fig. 3. Scheme for the galvanometric experiment [8, 9]: 1) electron beam; 2) collimator; 3) current monitor; 4) collector; 5) face electrode; 6) sample; 7) contact film; 8) back electrode; 9) Faraday cylinder; 10) galvanometer.

Fig. 4. Dependence of the charge Q transferred by the emission current on the charge density Qb in the beam absorbed by a NaCl sample with an anode-collector voltage of +150 V.

The experimental scheme is shown in Fig. 1 [4, 5]. The source of the primary electron beam was a Van de Graaf generator (1-2 MeV), 1-6 mA/cm², 40-50 μsec) placed vertically. Under it there was an insulated metal stage, on which the sample was placed. The metal stage was coupled by a capacitor. The charge accumulated in the capacitor during the time of irradiation gave the integral of the charge introduced into the sample. A probing electron beam passed across the surface of the dielectric and then passed between horizontal deflecting plates and fell upon a fluorescent screen. During the process of its charging the dielectric surface acts like the vertical deflecting plate of an oscilloscope. Therefore on the screen one can judge the change of the field over the sample surface according to the deflection of the probing electron beam. On one side of the experimental chamber there was a flat current collector intended for detecting secondary particles emitted from the sample surface during irradiation. The face of the sample was photographed through an optical window of the experimental chamber using photographic equipment.

With increased sample charging the probing beam was deflected upward which indicates growth of the field external to the sample created by charge absorption. Up to 10⁶ V/cm the growth of the field is quite stable and corresponds to complete