Scanning Electron Microscopy

Volume 1985
Number 1 *1985*

Article 18

11-13-1984

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SCANNING ELECTRON MICROSCOPY/1985/I (Pages 179-182) 0586-5581/85$1.00+.05
SEM Inc., AMF O'Hare (Chicago), IL 60666 USA

STUDY BY SCANNING ELECTRON MICROSCOPY AND ELECTRON SPECTROSCOPY OF THE CASCADE OF ELECTRON MULTIPLICATION IN AN INSULATOR SUBMITTED TO AN ELECTRIC FIELD

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(Paper received March 22 1984, Completed manuscript received November 13 1984)

Abstract

An original method for revealing the dielectric heterogeneities on an insulating surface has been developed on creation of an electron multiplication cascade inside the insulator placed in an electric field. The steps of the physical process are: (i) excitation of electrons into the conduction band, (ii) electric field acceleration of the conduction electrons, (iii) ionization of the valence levels, (iv) creation of many more new defects in the vicinity of dielectric heterogeneities, (v) charge localization on defects and appearance of a local residual potential. The potential map is observable by scanning electron microscopy after propagation of the ionizing cascade, but only during the first scan which smoothes the surface potential. By electron spectroscopy the energy of the secondary negative particles emitted during the cascade can be analysed.

Key Words: Electron Spectroscopy, Cascade, Insulator, Multiphoton.

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Introduction

The low conductivity of an insulator is due to the lack of allowed levels near the top of the valence band. However, as the phenomenon of photoconduction shows it, an electron excited into the conduction band can move under an electric field. The purpose of this work is to observe the results of cascades of inelastic collisions when the excited electrons have got enough energy to produce interband transitions. This work lies in the scope of dielectric breakdown and surface flashover.

Experiment

All the experiments described here are achieved in a vacuum of 10^{-9} Torr on pure amorphous silica, containing less than 10 ppm OH and other impurities.

Multiphoton absorption

The silica is irradiated by a high fluence laser with 2.34 or 3.5 eV energy. The electron emission from the surface is measured by a spherical analyser. When the injected power reaches a critical value of around 1 GW/cm^2, an intense emission is observed which saturates the multichannel detector and which cannot be mistaken at all for a multiphoton process (Yen, 1980; Bensoussan, 1983) (Figure 1). The energy spectrum reveals a shift reflecting the creation of a positive charge of a few volts in the irradiated area.

Electron bombardment

The glass sample is bombarded by an electron beam of 20 keV primary energy, 5.10^{-8} A primary current, 100 microns spot diameter, during one minute. The glass charges up negatively up to a local potential of approximately 17 keV, creating a "mirror" effect. This effect used for measuring the potential distribution around the spot point has already been exposed elsewhere (Le Gressus, 1984).

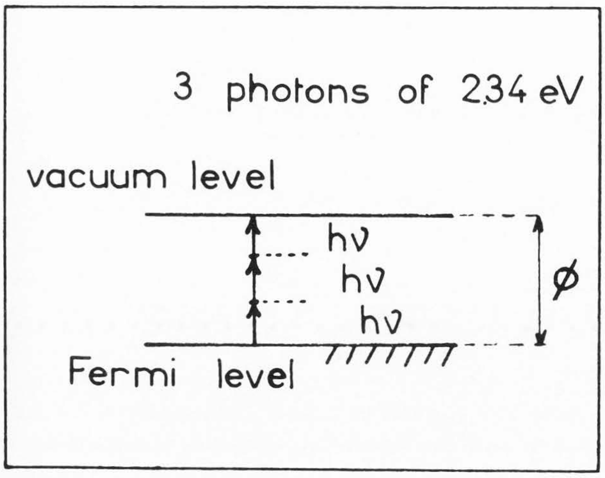

Fig. 1. Multiphoton process. A very high density of photons can excite an electron to an empty level above the vacuum level (photon energy of the laser 2.34 eV).

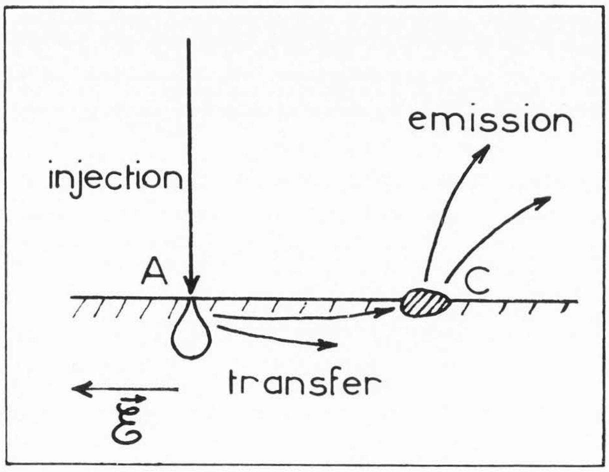

Fig. 2. Secondary electron emission from dielectric heterogeneities on the surface. The emission point C is at a distance of a few tens of microns from the injection point.

This negative charge A builds in the solid and in the vacuum above it a high field of around 10^5 V.cm^{-1}. In a second step, the surface is bombarded on the B-point which is at a V_B potential due to charge A, and straight away the secondary electron image of the whole sample shows zones of contrast (Figure 2 and Figure 3) which are erased by the first scan. These constrasts are reproducible when the sequence injection - scan is repeated (The charge A still remains). When the surface is bombarded at the B point, the spectrum of the emitted electrons exhibits P-"ghost" peaks whose energy is smaller than the V_B threshold value. These peaks are observable with any type of electron analyser and are suppressed after annealing the sample at a temperature greater than 300°C (Figure 4).

In this experiment, one observes the remote emission of particles, at a distance from the injecting point which is much higher than the electron diffusion length in an insulator allows it.

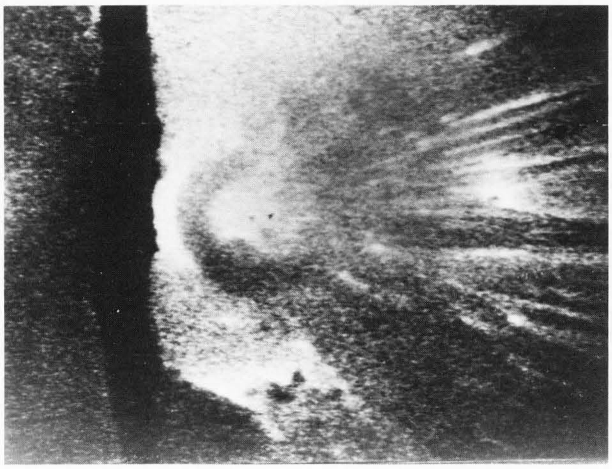

Fig. 3. Secondary electron picture of the electron cascade. The electric field is given by a negative charge (mirror) on the left side. The rays come from the dielectric heterogeneities.

Discussion

In order to understand the observed contrast and the remote emission of particles, we study the mechanisms of charging up and the nature of the charged sites.

The appearance of the negative charges corresponds to the localization of electrons on precursor states to E'-centers or peroxy linkages induced by oxygen vacancies in the SiO_2 tetrahedra (Vigouroux, 1984). The sensitivity of silica to electron simulated creation of defects favours creation of traps which appear preferably in the areas of high density electron bombardment. In presence of an electric field, the electrons injected into the conduction band (by electronic excitation or multiphoton absorption) are accelerated at 1 meV/A approximately until they acquire enough

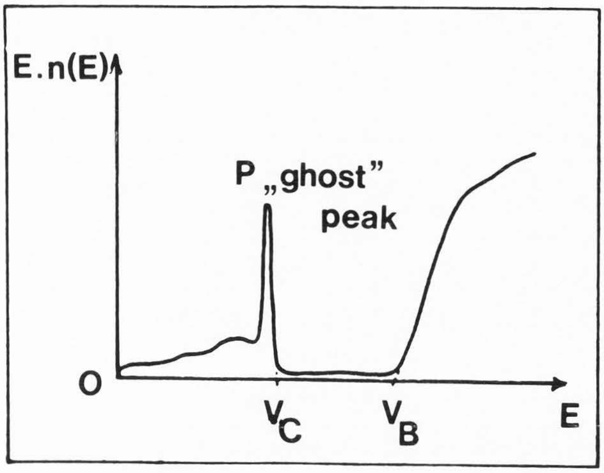

Fig. 4. Spectrum of the emitted electrons during the propagation. The P-peaks correspond to electrons emitted from the C-point.

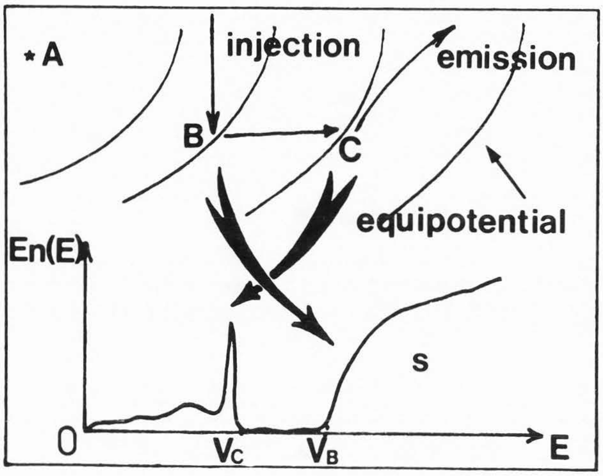

Fig.5. Measurement of electron emission into the vacuum associated with the propagation of the discharge. When the surface is bombarded at the B-point the expected spectrum is only the right part (s). A secondary electron emission appears in C which induces the P-"ghost" peaks at a V_C potential.

energy to ionize the valence electrons of atoms on their trajectory. A cascade of multiplication then arises and the emitted electrons are collected by the analyser. Their emission point is C, further away from the B injection point (Figure 5), after having been multiplied on the traject B - C. The C-point is situated on the V_C equipotential. Electrons will be emitted in C only if the component of the electric field in C builds with the surface such an angle that the electrons are not reflected by the surface barrier. The direction and the value of the electric field drastically depend on the dielectric constant in C. Hence the high dielectric constant zones will be of low field and low potential so that the electrons will be focused to them. In the vicinity of impurities there will be increase of damage and charge, producing the observed contrasts. They are erased by the first scan because all the injected electrons in B have moved away under the electric field.

The photoemission under laser irradiation clearly indicates an emission of electrons which cannot be due to ionization of valence electrons as they would not have enough energy to drop out of the solid. The secondary electrons emitted from the C-point may originate from a recombination process successive to defect and electron-hole pairs creation. This explanation is confirmed by the cathodoluminescence process (Figure 6).

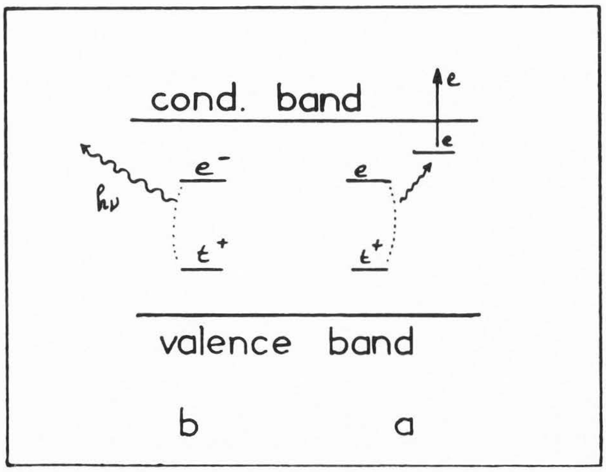

Fig. 6. Electron-hole pair recombinations (a) radiative process, (b) non-radiative process.

Conclusion

It would be very interesting to know more about the nature of the observed heterogeneities but the direct measure appears impossible because of the great damage induced by the beam. The next step of the study will be a local measure of the dielectric constant and a better knowledge of the P-ghost peak.

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