DEVELOPMENT AND CHARACTERIZATION OF SEMICONDUCTOR GAS DISCHARGE MICROSTRUCTURE

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In a semiconductor gas discharge structure (*SGDS*) with diameters much larger than an inter-electrode distance, the effects of different parameters (electrodes separation, gas pressure, diameter and conductivity of the *GaAs* photodetector, etc) on electrical breakdown and current oscillations of the current have been studied. Instabilities of spatially non-uniform distributions resulting in the formation of multiple current filaments with increasing voltages above the critical values have been observed.

1. INTRODUCTION.

Presently, there exist a special interest in semi-insulating (*SI*) *GaAs* crystal properties as these crystals become promising for radiation detector applications [1] and *SI GaAs* has an increasing relevance, e.g., as a particle detector [2,3] and for optical data storage. The study of instabilities in semiconductors has been a field of intense interest and most of the instabilities display spatiotemporal patterns. Electrical non-linearities in semiconductors are good examples of non-integrable systems since they present a rich variety of complex behavior. The theory [4] and experiment [5] showed that the current flowing through a semiconductor can oscillate if a sufficiently high dc bias is applied to the sample. These oscillations are caused by domains of high electric field that travel from cathode to anode [6]. This paper quantitatively investigates the spatial distribution of the current density formed as a result of loss of stability of a homogeneous current state in a high-resistivity *GaAs* photodetector subjected to strong electric fields.

2.EXPERIMENTAL.

A gas layer is sandwiched between the glass plate and the semiconductor plate in Fig.1b. Both structures (see Fig.1a and b) sequentially operate with the same *GaAs* photodetector. In the experiments, a *Cr*-doped *SI GaAs* [7], an *n*-type high resistivity ($\rho \sim 10^8$ Ωcm) plate oriented (100) in the plane of natural growth of the crystal, is used as a semiconducting photodetector. The diameter and the thickness of the *GaAs* photodetector are 50 mm and 1 mm, respectively. On the illuminated side of the photodetector, a conducting vacuum-evaporated *Ni*-layer with approximately 40 nm thick is coated. The anode is a disc of glass (with 50 mm diameter and 2 mm thickness) coated with a thin layer of a transparent conductor SnO_2 . The sheet resistance of the SnO_2 layer is at the range of 15 and 20 Ω/ sq and this value for *Ni* film is of the order of 10 Ω/ sq. The surface of the semiconductor cathode was separated from a flat anode by an insulating mica sheet with a circular aperture at its centre. Changeable thickness of the insulator makes it possible to vary the size of the interelectrode air gap, *d*, between 45 and 525 μm. Typical diameters of the active electrode areas, *D* (i.e. gas discharge gap or diameters of the circular through-aperture in the insulator) are 5, 9, 12, 18 and 22 mm.. For further details regarding to the experimental setup, see [8].

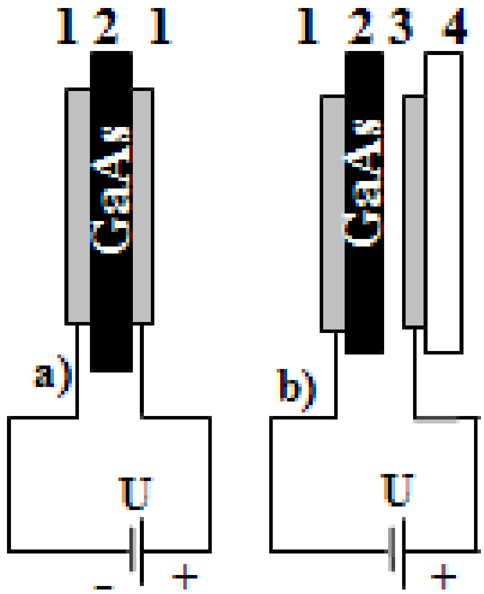

Fig.1. Investigated structure (a) in the absence and (b) in the presence of a gas discharge gap: 1 - *Ni* contact; 2 – *GaAs* photodetector; 3 – gas discharge gap; 4 - anode

3. RESULTS AND DİSCUSSİON

We assume that a *homogeneous stationary* Townsend discharge [9] is established in the *SGDS*. From the physical point of view, the most important feature of this kind of gas discharge is that space charge effects inside the gap are small and do not cause a distortion in the electric field between the electrodes. Another characteristic property is the homogeneous distribution of the current density perpendicular to the current flow. A local change of a semiconducting cathode resistance leads to a local change of the current and the *DLE* [10]. The current instabilities occur when the voltage drop at the gas discharge is constant and the semiconductor operates in the nonlinear regime. They occur due to the nonlinearity of the semiconductor cathode, while the gas discharge serves to visualize transport processes in *GaAs*. The effect has been interpreted in the cited work as being due to the electrical domain instability in the semiconductor electrode caused by the *N*-type *CVC* of the electrode [6]. This kind of transport nonlinearity is known to be responsible for propagating high electric- field domains in *SI GaAs* (see, e.g., [6]).

When the voltage V_0 approaches to the threshold level V_{cr} from below, the current I in the structures exhibits oscillations of a relatively small amplitude. Such a behavior of *SI-GaAs* samples have been observed previously (see, e.g., recent review [11] devoted to the problem of domain instability in *SI GaAs*).As demonstrated in Fig.2a, the potential drop across the discharge gap in this range is nearly constant and the electric field increases only on the *SI GaAs* photodetector [12]. The curves ρ_1, ρ_2 and ρ_3 in Fig.2a represent the *CVC* (i.e. in darkness and under a weak and a maximum illumination intensities of light L_1 and L_2, respectively) when the resistivity of the *SI GaAs* photodetector is decreased from ρ_1 = 1.3x10^8 Ωcm to ρ_3 = 4x10^7 Ωcm through illumination.

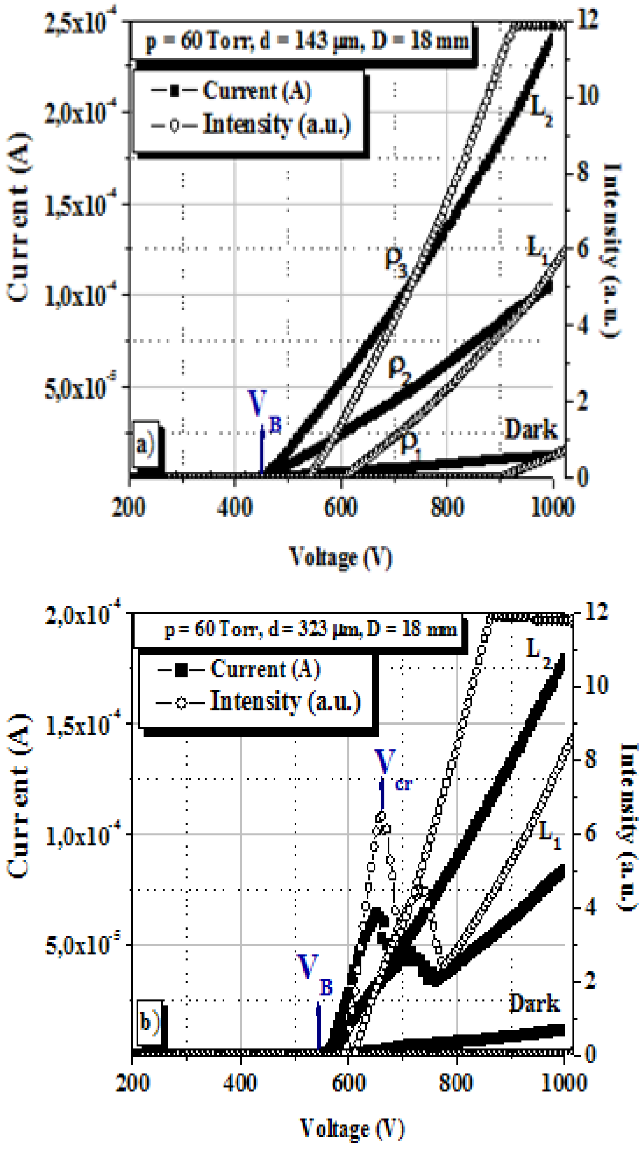

Fig.2a,b. *CVCs* of a planar discharge cell in darkness and under a weak and a maximum illumination intensities of light L_1 and L_2, respectively: a) The curves ρ_1 - ρ_3 represent the *CVC* for three resistivities of the *SI GaAs* photodetector for d = 143 µm; b) *CVCs* with *N*-type *NDC* of the *SI GaAs* photodetector for electrode separation d = 323 µm.

Moreover, the shape of the *CVC* in a system depends on the voltage increase of the power supply and the illumination intensity [7,13]. It should be noted that *CVCs* of *SI GaAs* photodetector shows ohmic behaviour for d = 143 µm. A further increase in the electrode seperation d beyond a certain threshold value (d = 323 µm) leads to the destabilization to a ohmic behaviour of *CVCs* of *SI GaAs* (see Fig.2b). Thus we claim this specific d value as a critical parameter in order to classify the dynamics of our system. Because beyond this critical electrode distance d (i.e. between 323 - 525 µm) we observed above- mentioned the pronounced *N*-like shape oscillatory behaviour in currents which yields to a oscillatory bifurcation from a stationary state (also see Fig.3). The curves measured possess a clearly pronounced *N*-like shape which manifests them as apparent scatter in a dc measurement. If the *CVC* of the photodetector is a nonmonotonic one, instability develops in a *SI GaAs*, which may initiate nonlinear electrical characteristics in the device. Such a case is considered in this work. Our system shows a rich variety of instabilities by varying experimental parameters (thickness, D and σ of the photodetector material, gas pressure, etc).

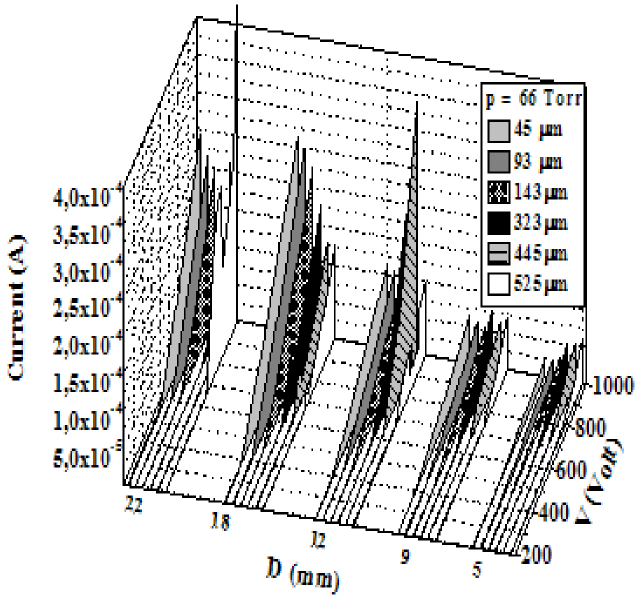

Fig.3. *CVCs* for different diameter D of detector areas under maximum illumination intensity of light L_2. Gas pressure p = 66 Torr.

4. CONCLUSION

SI GaAs photodetector, biased with dc voltages larger than a fixed critical voltage, shows oscillations in the current due to the presence of a high-field domain, which forms at the photocathode, propagates in the bulk, and disappears at the anode. The presence of the deep electronic levels of defects, the so called *EL*2 centers, gives rise to the *N*-type *NDC* of the material, as a consequence, to oscillations in current when a dc voltage of a high enough magnitude is applied to a *GaAs* photodetector. A comparative study of the steady-state properties of two semiconductor structures (in one of them the anode is a gas discharge region and in the other it is an evaporated metal electrode) demonstrates that the instability of a spatially uniform distribution of the current observed in the structure with a discharge gap is due to the effects which take place in the photodetector. It is shown that under the suitable experimental conditions the discharge gap only plays a passive role and is not responsible for the appearance of the instability.

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