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Enhancement of the Resolution of a Semiconductor Photographic System in a Magnetic Field

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ABSTRACT

A method is described for enhancing the resolution R of a semiconductor photographic system by subjecting it to a homogeneous magnetic field. Bi has been chosen as the photographic plate, since it has a large value of the cathode sputtering coefficient which is important in the formation of image by charged particle flux. A considerable increase of the resolution is observed when the applied magnetic field is parallel to the electric field between the electrodes. Effect of the magnetic field on the I – V characteristic of the system is discussed.

Introduction

Photoionization systems with semiconducting electrodes have found interesting applications in the last decade, especially in the registration of infra-red (IR) images.[1–4] High speed photography, non-silver image formation and rapid control of resistivity inhomogeneties in semiconductor plates are other interesting utilizations of these systems.[2–5] To optimize some of the parameters of the system, further developments are still needed in the above mentioned applications. The optimization can be achieved by detailed studies of the physical mechanisms involved in the process and by the stabilization and regulation of the discharge current.

The ionization system[6] with a plasma-semiconductor interface as the current conductor, was first used as an image converter. In this type of converter, the plasma-semiconductor electrical contact plays a significant role in the treatment of the surface at the interface. Use of this technology of gas discharge surface treatment has increased extensively in the last ten years. Some of its applications can be summarized as: plasma etching, plasma-reactive evaporation of dielectrical, conductive and special optical films and ionic plasma sputtering.

The ionization-type photographic systems with a semiconductive electrode have used only the gas discharge luminescence for the visualization of the IR image, so far. However, there is also another possible mechanism, the so-called secondary radiation, i.e., the flux of the charged plasma particles. In Kirlian-photography, which uses this mechanism, the image is formed by the interaction of plasma with a photosensitive layer.[7] Actually, in this photography both of the interactions between the object and image fixing surface are used, i.e. the plasma luminescence and the direct interactions of the charged particles. Grinberg *et al*,[8] calculated the spatial frequency response of a semiconductor photographic system with a p-n junction. The results of their theoretical calculations showed that an improvement in the characteristic by enhancement of the resolution R may be possible by reduction of the thickness of the various layers in the system. However, in most of the cases it is not practical nor easy to change the thicknesses of the layers. They also showed that application of a homogeneous magnetic field can improve the resolution on the surface of the GaAs electrode by transverse spreading of the minority carriers. The results of their calculations yielded a resolution of 605 lines/mm under the action of 30 *kOe* whereas it was 286 lines/mm without the magnetic field.

In the present paper we suggest and discuss a method for enhancing the resolution R of an ionization type photographic system by subjecting it to a homogeneous magnetic field, to search for the possibilities of non-silver image formation. The effect of the presence of a magnetic field on the $I-V$ characteristic of the system are discussed.

Experimental

In our system, Bi has been chosen as the photographic plate, since it has a large value of the cathode sputtering coefficient which is important in the formation of image by charged particle flux. The system (Fig. 1) contains a semiconductive photosensitive electrode of high resistivity GaAs plate (4) coated by a transparent conducting layer of Ni (3). The diameter of the GaAs is 30 mm and the thickness is 1.2 mm. The crystal is photosensitive up to 0.89 μm and has resistivity of 10^6 Ω cm. On the illuminated side of the GaAs a transparent vacuum evaporated Ni electrode (3) is coated, having absorption of radiation between 25–40% in the spectral range 0.9 to 1.3 μm, and electrical resistance of a few tens of ohms. The air gap (5) has a thickness of about 40–60 μm and the pressure P is approximately 6.7 10^3 Pa. The counter-electrode is a disk of glass (8) coated with a thin layer of a transparent conductor (7) (SnO_2 with ~ 50 Ω surface resistance) and a layer of Bi (6) for the formation of the image on top. The Bi film deposited by vacuum evaporation is 0.5 to 1.4 μm thick with an initial optical density of 1–2. A constant electric potential of 600 V is applied to the electrodes. The object (2), which is illuminated with parallel light, is placed between the IR source (1) and the surface of the semiconductive electrode.

A local change of the resistivity of the semiconductor plate leads to a local change in the current and, as a result, the gas-discharge luminescence in the gap is affected. Therefore, one of the parameters

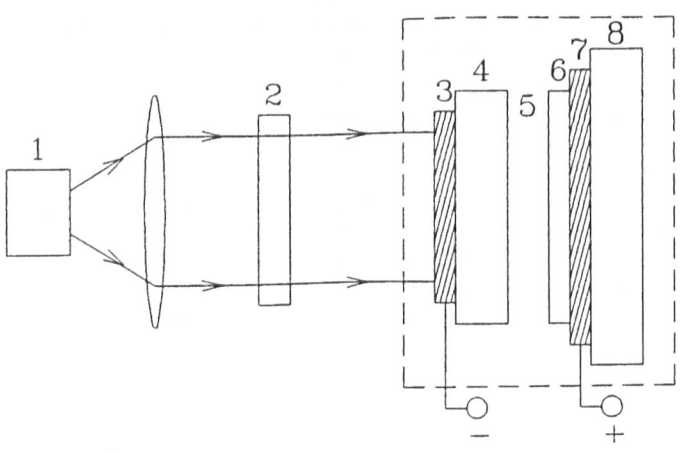


Fig. 1. A schematic representation of the photoionization system.

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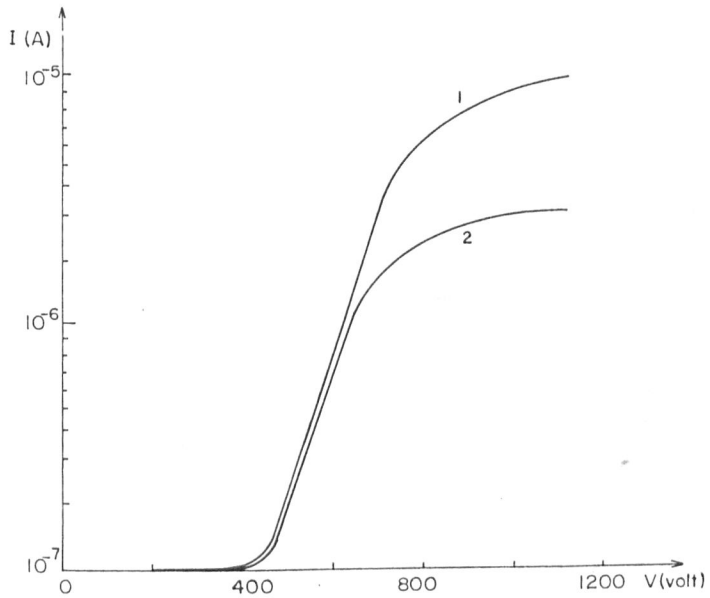


Fig. 2. I–V characteristic with (curve 2) and without (curve 1) the magnetic field.

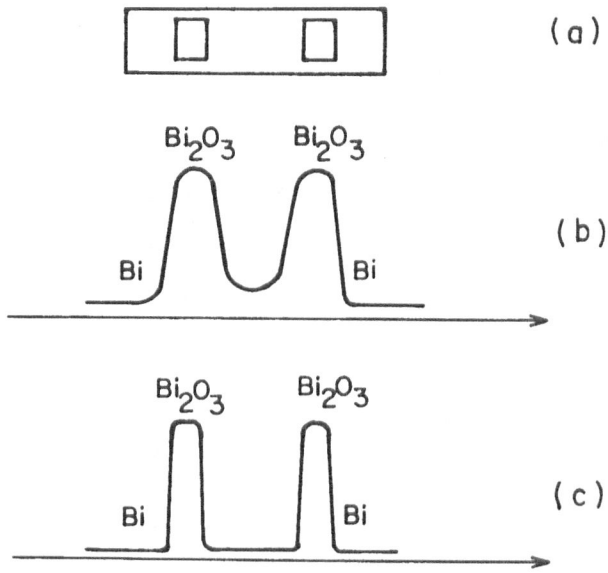


Fig. 3. Image of an object (a), without (b) and with (c) magnetic field.

of the system is the uniformity of the resistivity distribution of the semiconductor electrode.[5] The image, however, is basically formed by physico-chemical interactions between the plasma in the gap and the Bi layer. The part of the object which transmits IR radiation increases the luminescence and the plasma surface interactions in the corresponding areas of the gap which result in the formation of the image.

The analysis showed that the image formed on Bi film during discharge luminescence was due to the formation of Bi_2O_3 on the surface.[4] The formation of image by this oxidizing reaction only occurs when the electrode having Bi film is the positive terminal, because the active components causing the reactions on the surface of the Bi film are the electrons and negative oxygen ions.

An electromagnet is used to produce the magnetic field. It has pole areas of approximately 25 cm^2 and the distance between the poles is approximately 10 cm. The photoionization cell is placed in the vicinity of the poles of the magnet at a point where the value of the magnetic induction B is 20 kOe. The direction of the magnetic field ($\vec{B}$) can be varied relative to the electric field strength ($\vec{E}$) between the electrodes of the cell, from 0 to 180°.

Results and Discussion

Fig. 2 shows the I–V characteristics of the semiconductor photographic system before and after the application of the magnetic field. These characteristics were measured at a constant voltage in the range of 0–1100 volts and it was found that the application of the magnetic field reduces the current through the system (curve 2 in Fig. 2). Maximum effect was observed if the direction of the magnetic field was parallel to the electric field across the electrodes. As can be seen from Fig. 2, the effect of the magnetic field (i.e., the reduction of the current) increases as the current increases. Quantitatively, current reduction under the action of the magnetic field is as follows: the current value of 9.5×10^{-5} A at 1100 V is reduced by 7% if magnetic field is present, while at 700 V the current value of 3×10^{-5} A is reduced by 4.5%. The value of the voltage at which the gas discharge glow begins (breakdown voltage) does not depend on the value of the magnetic field.

The results of photography under the action of a magnetic field sw that the most effective orientation of the magnetic induction and the electric field between the electrodes is $\vec{B} \,||\, \vec{E}$. Fig. 3 shows the object used (a) and the transmission profiles of the Bi film with (c) and without (b) the magnetic field, from which a significant modification of the image resolution can be observed when the magnetic field is present. The object has two rectangular holes of dimension 2 mm and the distance between these holes is 8 mm. These transmission profiles were obtained using a standard densitometer after the Bi film was taken out. As stated above, in the regions corresponding to the rectangular holes on the Bi film, a Bi_2O_3 layer is formed and this layer has approximately 90% larger transmittance in the visible spectrum than Bi.[4] Estimates of the resolution on the Bi film were made using standard photographic strips. When the magnetic field of 20 kOe is present, the highest contrast with a resolution up to 12 lines/mm was achieved for thin (~ 0.5 μm) films, whereas it was 5 lines/mm without the magnetic field.

Thus, the effect of magnetic field on the performance of the photographic ionization system can be summarized by two experimental observations: (1) improvement of the resolution of the image produced on the Bi film; (2) decrease of the discharge current. These results can be qualitatively interpreted in terms of the focussing of the particle flux (negative ions and electrons) by the magnetic field. In a focussed beam, scattering efficiency is larger in comparison with the non-focussed case, due to the increased number of collisions. As a result of that, one can expect reduction in the mobility of carriers which causes a decrease in the current.

In conclusion, the resolution of such a system can further be increased by using different electrodes having better photosensitivity and suitable resistivity. Also, absorption and reflection losses of the electrodes can be decreased using different material options.

Acknowledgement

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