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ELECTRICAL AND PHOTOVOLTAIC PROPERTIES OF A BISMUTH-(Ga_2Se_3-In_2Se_3) METAL-SEMICONDUCTOR CONTACT

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Electrical and photovoltaic properties of a metal-semiconductor contact between bismuth and a semiconductor alloy (Ga_2Se_3-In_2Se_3) are studied. The contact shows rectifying behaviour. Its d. c. current-voltage characteristics are measured in the dark and under illumination. The photovoltaic spectral response shows a band peaking at 2.3 eV with a long tail towards lower energies (above 1.1 eV).

Semiconductor alloys formed by solid solution between Ga_2Se_3 and α-In_2Se_3 (R)* have recently been investigated in this laboratory[1,2]. In the whole range of concentrations, four distinct phases stable at room temperature have been established. The alloy Ga_2Se_3 (40 mol %) and In_2Se_3 (60 mol %), which belongs to the γ_1 phase and which exhibits intensive photoconductive properties, has been chosen to form a metal-semiconductor contact with bismuth. The properties of the contact are studied in this work.

Room-temperature phases of Ga_2Se_3 and In_2Se_3(R) were prepared by direct synthesis of pure elements in stoichiometric proportions at 1025 and 915°C, respectively, in evacuated and sealed quartz tubes. The alloy Ga_2Se_3 (40 mol %) - - In_2Se_3 (60 mol %) was prepared in a silica tube by melting the appropriate molar weights of the compounds at 1070 °C. The ingot thus obtained was polycrystalline with transparent single-crystal grains of a few mm in size. Single-crystal samples were polished with alumina powder to form planeparallel platelets about 300 μm

* α is the room-temperature phase of In_2Se_3 which is rhombohedral (R).

thick; the platelets were weak n-type with a room-temperature electrical resistivity of $\approx 10^9$ Ωm. Rectifying structures were obtained by thermal evaporation of bismuth onto the (Ga_2Se_3-In_2Se_3) platelet. The back contact was made by depositing indium film; it was established that the contact (Ga_2Se_3-In_2Se_3) with indium is ohmic. Bismuth-semiconductor contact area was 4×10^{-6} m^2.

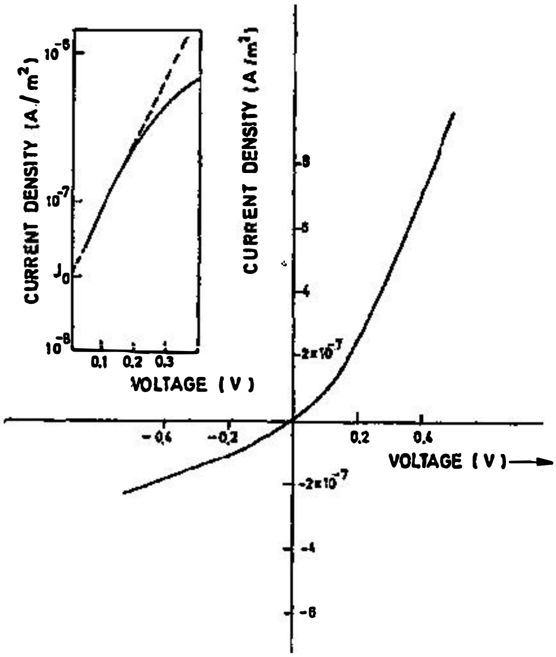


Fig. 1. Current density-voltage characteristic of the bismuth-n-(Ga_2Se_3-In_2Se_3) contact in the dark. The inset shows the semilogarithmic plot in the forward bias region.

Fig. 1 shows the room-temperature dark J-V characteristic of a bismuth-n--(Ga_2Se_3-In_2Se_3) contact. The contact exhibits rectifying behaviour and the forward current flows when bismuth is biased positively with respect to the semiconductor. The semilogarithmic plot of the forward charachteristic drawn in the inset to Fig. 1 shows more clearly the dependence of the current density J on the bias voltage V. At low bias voltages this dependence has the form of a current--voltage relation for a Schottky-barrier diode[3]:

$$J = J_0 \, [\exp(eV/nkT) - 1]. \tag{1}$$

Here e is the electron charge, k the Boltzmann constant, T the absolute temperature, n an experimentally determined factor called the diode quality factor and J_0 the saturation current density given by the realation,

$$J_0 = A^* T^2 \, [\exp(-e\Phi_{Bn}/kT)], \tag{2}$$

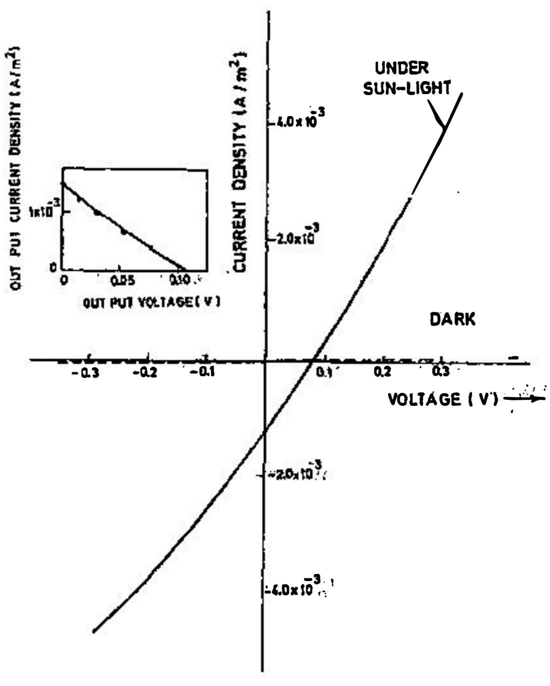
where $e\, \Phi_{Bn}$ is the barrier height between the metal and the n-type semiconductor while A^* is the effective Richardson constant. The value J_0 derived from Fig. 1 at the zero bias voltage intercept was found to be $3 \times 10^{-8} Am^{-2}$. The value of the factor n calculated from the slope of the $\log J$ vs V curve was 3.0. The barrier height $e\Phi_{Bn}$ from the relation (2) was found to be 1.10eV, while A^* was taken as $A^* = 1.2 \times 10^{6} Am^{-2} K^{-2}$.

In the higher bias region the J-V characteristic shows a deviation from the linear dependence of the $\log J$ vs V curve (Fig. 1). This behaviour might be related to the high resistivity of the semiconductor material and to the high series resistance.

By applying the expression of the form

$$I = I_0 \{\exp\, [e(V - IR_s) / nkT] - 1\}, \tag{3}$$

where R_s is the series resistance, we fitted expression (3) to the experimental current-voltage curve of Fig. 1 and obtained $n = 3.0$ and $R_s = 4.735 \times 10^{10}\ \Omega$ for the diode quality factor and the series resistance, respectively, while I_0 was taken as $I_0 = 1.2 \times 10^{-13}$ A. R_s so obtained is of the same order of magnitude as the resistance of the bulk semiconductor material. High diode quality factor (n = = 3.0) also indicates a deviation from the ideal Schottky diode behaviour[4].



g. 2. Current density-voltage characteristic for the bismuth-n-(Ga_2Se_3-In_2Se_3) contact under illumination. The inset shows the output characteristic of the contact under direct sun illumination.

Fig. 2 shows a typical J-V characteristic of a bismuth-n-(Ga_2Se_3-In_2Se_3) contact when bismuth film was illuminated with direct sunlight (flux $\approx$ 349 Wm^{-2}) and when it was in the dark. The inset to Fig. 2 shows the output current density--voltage characteristic under approximately equal sunlight illumination. The open-circuit voltage V_{oc} was equal to 0.1 V, while the shortcircuit current density J_{sc} was 1.4×10^{-3} Am^{-2}. A fill factor of $\approx$ 30 % was determined from this figure.

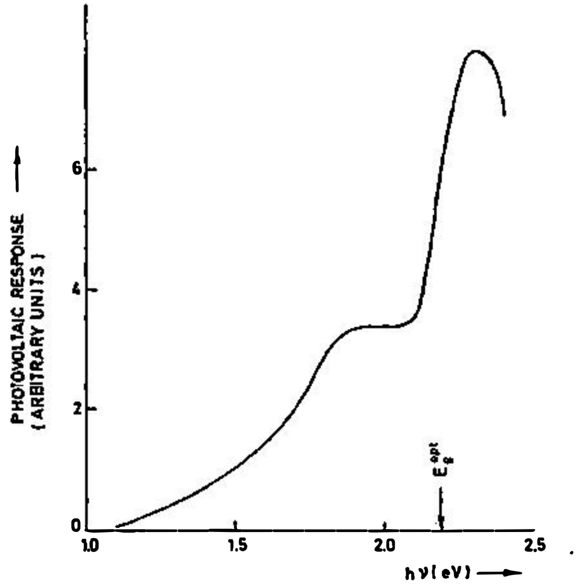


Fig. 3. The spectral response of the open circuit voltage V_{oc} of the bismuth-n-(Ga_2Se_3-In_2Se_3) contact. The optical band gap E_g^{opt} of the semiconductor is shown by an arrow.

The photovoltaic spectral response for a bismuth-n (Ga_2Se -In_2Se) contact is represented in Fig. 3. The response increases at photon energies higher than 1.1eV. This value was derived from the dark current-voltage characteristic as the barrier height $e\Phi_{Bn}$ between bismuth and n-(Ga_2Se_3-In_2Se_3). At higher photon energies there is a band peaking at about 2.3 eV. This value lies close to the optical energy gap of (Ga_2Se_3-In_2Se_3) which was found to be 2.18 eV[5]. The band at 2.3 eV is presumably related to the across-gap pair generation, while a large tail extending towards lower photon energies (the low energy threshold of about 1.1 eV) might be associated with the migration of hot electrons from the metal over the barrier into the semiconductor[6]. The shoulder near 2.0 eV in the spectral photovoltaic response curve is related to the allowed indirect optical transitions which exist in the semiconductor alloy Ga_2Se_3(40 mol %) -In_2Se_3 (60 mol %) at this photon energy[5].

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ELEKTRIČNA I FOTOVOLTAIČNA SVOJSTVA BIZMUT-(Ga_2Se_3-In_2Se_3) METAL-POLUVODIČ KONTAKTA

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Ispitana su neka električna i fotovoltaična svojstva kontakta metal-poluvodič između bizmuta i poluvodičke legure (Ga_2Se_3-In_2Se_3). Kontakt ima ispravljački karakter. Istosmjerne strujno-naponske karakteristike određuju se u mraku i na svjetlu. Fotovoltaični spektralni odgovor pokazuje pojas, koji ima vrh kod 2,3 eV sa dugim produžetkom prema nižim energijama (iznad 1,1 eV).