EMISSION CURRENTS IN DIODE STRUCTURES ON GALLIUM ARSENIDE FILMS

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Abstract

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EMISSION CURRENTS IN DIODE STRUCTURES ON GALLIUM ARSENIDE FILMS

1. For the development of dielectric electronics ([1,2]), materials with a wide forbidden band and high mobility are important; moreover, thin films must be made from these materials. Gallium arsenide, having a forbidden band of 1.35 eV and mobilities in single crystals of 8500 and 400 $cm^2/V \cdot sec$ ([3]), p. 190, respectively for electrons and holes, is one of the most promising materials.

In recent years work has been carried out on obtaining and studying gallium arsenide films on an insulating substrate ([4–11]). Mainly structural, optical, and, in part, electrical properties have been investigated.

The purpose of the present work was to obtain and study sandwich structures on high-resistance gallium arsenide films, analogous to sandwich structures on cadmium sulfide, to whose fabrication, study, and application numerous works have been devoted ([12–15]). At the same time, we investigated the optical and photoelectric properties of GaAs films deposited on an insulating substrate.

The sandwich structures were fabricated on fused-quartz substrates, on which aluminum electrodes had first been deposited in vacuum at $2{\cdot}10^{-7}$ torr. Then, in another chamber at $5{\cdot}10^{-7}$ torr, a gallium arsenide film ($\sim 1{\div}5\,\mu$) was applied by evaporation onto the aluminum electrode, and electrodes of aluminum, silver, and indium were deposited on top. p-type GaAs films with a resistivity of $10^4 \div 10^6\ \Omega \cdot$ cm were obtained by evaporation from a piece of low-resistance polycrystalline GaAs placed in a tantalum crucible. The deposition time of the gallium arsenide film was $\sim$ 10 sec. The crucible temperature was 1250°; the substrate temperature about 400°. In their construction, the structures made were similar to the CdS sandwich structures described in ([16]).

Electron diffraction studies showed that both on quartz and on a metallic substrate (aluminum electrode) polycrystalline gallium arsenide films were obtained, with no additional lines due to nonstoichiometry being observed.

In the present note only results obtained on symmetric sandwich structures with two aluminum contacts are reported. As is seen from the current-voltage characteristics (Fig. 1), in the voltage region $0.1 \div 10$ V the dependence of

Fig. 1 and Fig. 2: graphs reproduced in the source page.

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current on voltage is quadratic, and at lower voltages it is linear. Such a form of the current-voltage characteristics is typical of currents limited by space charge in dielectrics with small but finite conductivity ($^{17-19}$).

From the formula for currents limited by space charge in dielectrics with shallow traps,

$$J = \frac{9A}{32\pi}\,\theta\varkappa\mu\,\frac{V^2}{L^3}, \tag{1}$$

where $\varkappa$ is the dielectric constant; μ is the mobility; V is the applied voltage; L and A are the thickness and cross section of the dielectric layer;

$$\theta = \frac{p}{p_t} = \frac{N_v}{N_t}e^{-E_t/kT}$$

is the ratio of the concentrations of free and bound charge carriers, one can determine, from the steady-state current-voltage characteristic, the effective drift mobility $\theta\mu$ (^{20}). According to $\cdots$

in order of magnitude it turns out to be equal to 1 cm^2/V $\cdot$ sec. An estimate of the value of μ was obtained by us from measurement of the temperature dependence of the specific dark conductivity of the films. The conductivity was measured along the film by means of the four-probe method in the temperature range $170 \div 500$°K. From the conductivity values

$$\sigma = q\mu N_v e^{-F/kT} \tag{2}$$

the position of the Fermi level was determined, $F = 0.37$ eV from the top of the valence band (Fig. 2). Assuming $N_v \sim 10^{18}$ cm^{-3} (^{3}, p. 87), we find $\mu = 1 \div 10$ cm^2/V $\cdot$ sec. Consequently, $\theta \sim 0.1 \div 1$, i.e., the trapping effect

Fig. 1. Current-voltage characteristic of a sandwich structure on gallium arsenide

Fig. 2. Temperature dependence of the dark conductivity $\sigma(T)$ (1) and photoconductivity $\Delta\sigma(T)$ (2) of gallium arsenide films

of the emitted carriers does not play a substantial role. A possible reason for this may be autocompensation of traps, as occurs in single crystals and films of cadmium sulfide ($^{21-22}$).

The circumstance that the quadratic dependence on voltage takes place over a wide interval of variation of the current values (~ 4 orders of magnitude) makes

Fig. 3. a—transmission spectrum of a gallium arsenide film; b—spectral dependence of the absorption coefficient k (1) and photoconductivity $\Delta\sigma$ (2)

Figure 2: Fig. 3. a—transmission spectrum of a gallium arsenide film; b—spectral dependence of the absorption coefficient k (1) and photoconductivity $\Delta\sigma$ (2)

it possible, with sufficient confidence, to identify this section of the current-voltage characteristic with a current limited by space charge. An additional argument in favor of such a conclusion is the agreement between the experimental and theoretical values of the voltage V_1 at which the linear current regime changes into the quadratic one. According to (^{17})

$$V_1 = \frac{32\pi}{9}\frac{p_0 q L^2}{\theta \varkappa}, \tag{3}$$

where p_0 is the equilibrium concentration of majority carriers. Determining $A\mu p_0$ from the linear, and $A\mu\theta$ from the quadratic portion of the current-voltage characteristic, we find p_0/θ. Substituting this value of p_0/θ into (3), we obtain that V_1 should be equal to ~ 0.1 V. This result is in good agreement with the experimental data (see Fig. 1).

2. In order to obtain as much information as possible about the physical properties of high-resistance gallium arsenide films prepared by the method described above, the spectral dependences of the absorption and refraction coefficients, as well as of the photoconductivity, were studied. For this purpose, on SF-4, SF-10, IKS-14, and IKS-12 spectrophotometers with an IPO-12 attachment for measuring reflection, transmission spectra in the range $\lambda 400 \div 2500$ m and reflection spectra in the range $\lambda 400 \div 6000$ m were recorded. In Fig. 3a a clearly expressed interference pattern is visible. From the transmission and reflection spectra of the films, k, n, and also the film thickness L were calculated. The intrinsic absorption edge (Fig. 3b) is broadened, and

as often occurs in films (^{7}), are shifted somewhat toward larger values of λ in comparison with single crystals.

The film thicknesses determined from the interference curves (Fig. 3a) agree with the values measured with MII-4 and MIS-11 microscopes. In addition, the very fact of obtaining a clear interference pattern indicates good optical homogeneity of the films.

Fig. 3. *a*—transmission spectrum of a gallium arsenide film; *b*—spectral dependence of the absorption coefficient k (1) and photoconductivity $\Delta\sigma$ (2)

Photoconductivity was measured by the usual circuit (^{24}) with modulated illumination of frequency 10 Hz.* The spectral dependence of the photoconductivity $\Delta\sigma(\lambda)$ was recorded (Fig. 3b), as well as the temperature dependence in nonmonochromatic light $\Delta\sigma(T)$ (Fig. 2), and the dependence of $\Delta\sigma$ on the illumination intensity and on the applied field. The photoconductivity maximum coincides with the edge of intrinsic absorption in the films, and the entire $\Delta\sigma(\lambda)$ curve is stretched and shifted into the red region in comparison with single-crystal gallium arsenide.

Over the entire investigated range of illuminations (up to $I \approx 10^6$ lux), the photoconductivity depends linearly on I and does not depend on the applied field. The experiment was carried out up to field strengths $E = 10^4$ V/cm.

In the interval from nitrogen temperatures to 250°K, a weak increase of photoconductivity with temperature is observed, while at $250 \div 500$°K $\Delta\sigma$ does not depend on temperature. Joint consideration of the temperature dependences of dark conductivity and photoconductivity (Fig. 2) also indicates that the passage of emission currents in the GaAs films we studied is determined by processes in the volume of the microcrystals, and not at their boundaries. Under a barrier mechanism of conduction, the dependence of photoconductivity on temperature should be as strong as the dependence of dark conductivity ([25]).

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* A. A. Sukhanov participated in the photoconductivity study.

Note: Figure translations are in progress. See original paper for figures.