ELECTROPHYSICAL PROPERTIES OF AMORPHOUS GALLIUM SELENIDE FILMS IN ALTERNATE ELECTRIC FIELDS

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ABSTRACT

Frequency dispersion of loss tangent (tan δ) and ac-conductivity (σ_{ac}) of prepared by evaporation GaSe amorphous films have been investigated at frequencies $f = 5\times10^4 - 3.5\times10^7$ Hz. It was shown that at $f > 2\times10^6$ Hz relaxation losses take place. It was established that hopping conduction near the Fermi level takes place in GaSe amorphous films at frequencies from 2×10^5 to 2×10^6 Hz. The density of localized states at the Fermi level ($N_F = 8.2\times10^{17}$ eV^{-1}cm^{-3}), the mean time for phonon-assisted tunneling ($\tau = 0.9$ μs) and the hopping distance (R = 45 Å) have been evaluated for GaSe amorphous films. For frequencies above 2×10^6 and up to 3.5×10^7 Hz $\sigma_{ac}(f) \sim f^{1.5}$.

Keywords: alternate electric field; amorphous materials; dielectric properties, electrical conductivity, frequency.

I. INTRODUCTION

GaSe-based materials, combining interesting electrical and optical properties, are potential candidates for use in various transducers, light modulators, and information storage units. Miniaturization of semiconductor devices engenders great interest in the preparation of thin amorphous GaSe films and investigation of their properties.

Earlier, we studied the electrical, optical, and photoelectrical properties of amorphous GaSe films over wide ranges of electric fields (up to the switching field) and temperatures. In [1], we studied switching in amorphous GaSe films.

Of some interest is the study of dielectric properties of the thin evaporated GaSe films in alternate electric fields. The investigation of electric properties of semiconductor materials in ac-electric field gives information about the nature of charge transport and localization states in forbidden gap. For the establishment of mechanism of charge transport it is necessary to know the frequency dependence of ac-conductivity. The aim of the given report is the investigation of frequency-dependent dielectric parameters of GaSe amorphous films and the establishment of mechanism of charge transport in alternate electric fields. It must be noted that an analysis of publicated works has shown the absence of such data on GaSe amorphous films.

II. EXPERIMENTAL TECHNIQUES

GaSe amorphous films were prepared by intermittent evaporation of pulverized material. By testing a range of process variables, we were able to select conditions for the reproducible preparation of amorphous GaSe. Weighed portions of fine-particle powder were evaporated in a VUP-2K vacuum system at a pressure of 10^{-3} Pa. To feed the material to the evaporator heated to 1238 – 1363 K, we used a vibratory facility. The films grew at a rate of 15 – 50 Å/s on dielectric substrates (glass or glass-ceramic) heated to 373 – 423 K. After subsequent annealing at 600 K for 30 – 60 min, the films were still amorphous. The temperature was measured with a Pt/Pt-Rh thermocouple to an accuracy of ± 1K.

The films were characterized by chemical analysis and electron diffraction. They had stoichiometric composition and lustrous surfaces, exhibited good adhesion to the substrate, were photosensitivie, and featured reproducible electrical properties. The electrical resistivity of the amorphous GaSe films at 298 K was equal to $\sim10^{13}$ Ω·cm.

Electron diffraction patterns showed very broad rings typical of amorphous structures.

The amorphous films were used to fabricate Al – GaSe – Al sandwich structures (Fig. 1).

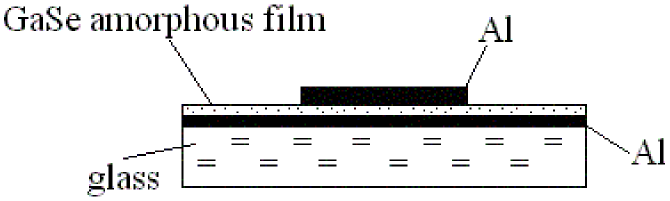

Fig. 1. Configuration of the sample on the base of GaSe amorphous film.

Contacts to both the substrate and the film were made by depositing aluminum, which exhibits good adhesion to GaSe. Film thickness, as evaluated from interference patterns in transmission spectra (MII-4 interferometer), ranged from 0.7 to 1.0 μm. Contact area was varied from 0.3 to 0.5 cm^2 (optical measurements with an MPSU-1 microscope).

Amorphous GaSe films could be prepared in the range of substrate temperatures from 373 to 423 K. At higher substrate temperatures, we obtained polycrystalline films consisting of hexagonal GaSe with lattice parameters $a = 3.74$ and $c = 15.95$ Å, in full accord with XRD data on polycrystalline GaSe (sp. gr. $P6_3$ / mmc – D_{6h}^{4} ; $a = 3.755$, $c = 15.94$ Å).

Measurements of the dielectric coefficients of GaSe amorphous films were performed at fixed frequencies in the range 5×10^4 – 3.5×10^7 Hz by the resonant method using a TESLA BM 560 Qmeter. For electrical measurements, the samples were placed in a specially constructed screened cell. All measurements were performed at T = 298 K. The accuracy in determining the resonance capacitance and quality factor Q = 1/ tan δ of the measuring circuit was limited by errors related to the resolution of the device readings. The accuracy of the capacitor graduation was ± 0.1 pF. The reproducibility of the resonance position was ± 0.2 pF in capacitance and ± (1.0 –1.5) scale divisions in quality factor.

III. EXPERIMENTAL RESULTS AND DISCUSSION

Fig. 2 shows the experimental frequency dependence of the dissipation factor tan δ for GaSe amorphous film. As it is seen from Fig. 2 the tan δ(f) curve has two branches: a monotonically descending one at $f = 5\times10^4 – 2\times10^6$ Hz and a rising one at $f = 2\times10^6 – 3.5\times10^7$ Hz . The hyperbolic decrease of tan δ with frequency is evidence of the fact, that conductivity loss becomes the main dielectric loss mechanism at $f < 2\times10^6$ Hz. Increasing branche of tan δ(f) curve in GaSe film allow us to confirm that relaxation losses take place at $f > 2\times10^6$ Hz.

Fig. 3 shows the experimentally measured frequency dependence of the ac conductivity of GaSe amorphous film at 298 K. For all investigated samples the magnitude of ac-conductivity is much greater than that of the dc hopping conductivity.

Ac-conductivity of GaSe amorphous films can be expressed by the following equation,

$$\sigma_{ac}(f) = \sigma_0 + \sigma_f, \qquad (1)$$

where σ_0 is dc conductivity and

$$\sigma_f = \sigma_1 + \sigma_2 + \sigma_3 \qquad (2)$$

In (2) σ_1 is very weak function of frequency; $\sigma_2 \sim f^{0.8}$, and $\sigma_3 \sim f^{\,1.5}$. The $\sigma_{ac} \sim f^{0.8}$ dependence indicates that the mechanism of charge transport is hopping over localized states near the Fermi level [2]. This charge transport mechanism is characterized by the following expression obtained in [3]:

$$\sigma_{ac}(f) = \frac{\pi^3}{96}\, e^2\, kT\, N_F^2\, a^5 f\left[\ln\left(\frac{\nu_{ph}}{f}\right)\right]^4, \qquad (3)$$

where e is the elementary charge, k is the Boltzmann constant, N_F is the density of localized states near the Fermi level, $a = 1/\alpha$ is the localization length, α is the decay parameter of the wave function of a localized charge carrier, $\Psi \sim e^{-\alpha r}$, and ν_{ph} is the phonon frequency. Using expression (3), we can calculate the density of states at the Fermi level from the measured values of the conductivity $\sigma_{ac}(f)$. Calculated value of N_F for investigated GaSe amorphous film was equal to 8.2×10^{17} $eV^{-1}\cdot cm^{-3}$. Localization radius chosen as 6.6 Å [4]. This value for a in GaSe amorphous film was obtained experimentally from results of study of dc-hopping conductivity.

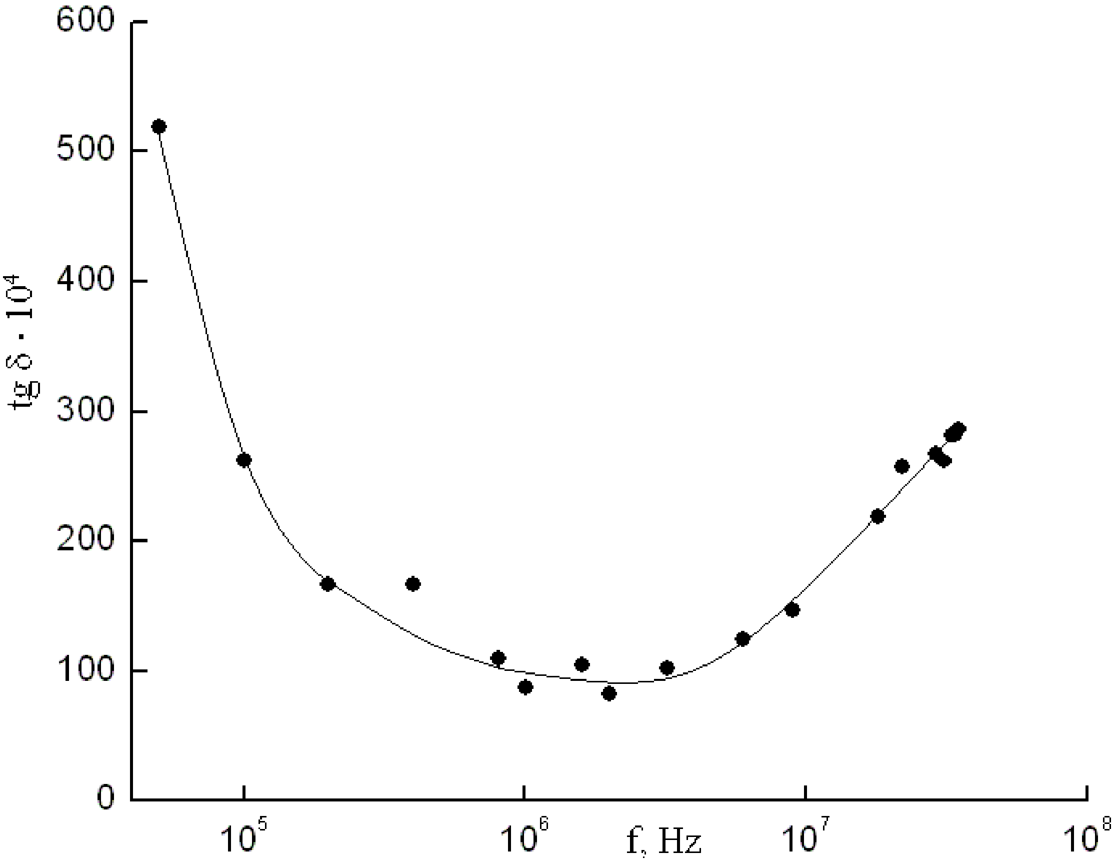

Fig. 2. Dispersion curve of tan δ in GaSe amorphous film at T = 298 K.

The theory of ac hopping conductivity provides an opportunity to determine the average time τ of charge carrier hopping from one localized state to another using the formula [2]:

$$\tau^{-1} = \nu_{ph} \exp(-2R\alpha), \qquad (4)$$

where R is the average hopping distance:

$$R = \frac{1}{2\alpha} \ln\left(\frac{\nu_{ph}}{f}\right) \qquad (5)$$

In (5) f is average frequency from interval, where $f^{0.8}$ law for ac hopping conductivity takes place. Calculated values of τ and R for GaSe amorphous film were 0.9 μs and 45 Å, correspondingly. It must be noted, that this average hopping distance R = 45 Å is in good agreement with results obtained from dc hopping conduction measurements [4] (R = 55 Å).

IV. CONCLUSIONS

Thus, the experimental results of high frequency dielectric measurements on GaSe amorphous films allow us to establish the nature of dielectric losses, the mechanisms of charge transport and to evaluate the density of localized states near the Fermi level, average hopping time and distance.

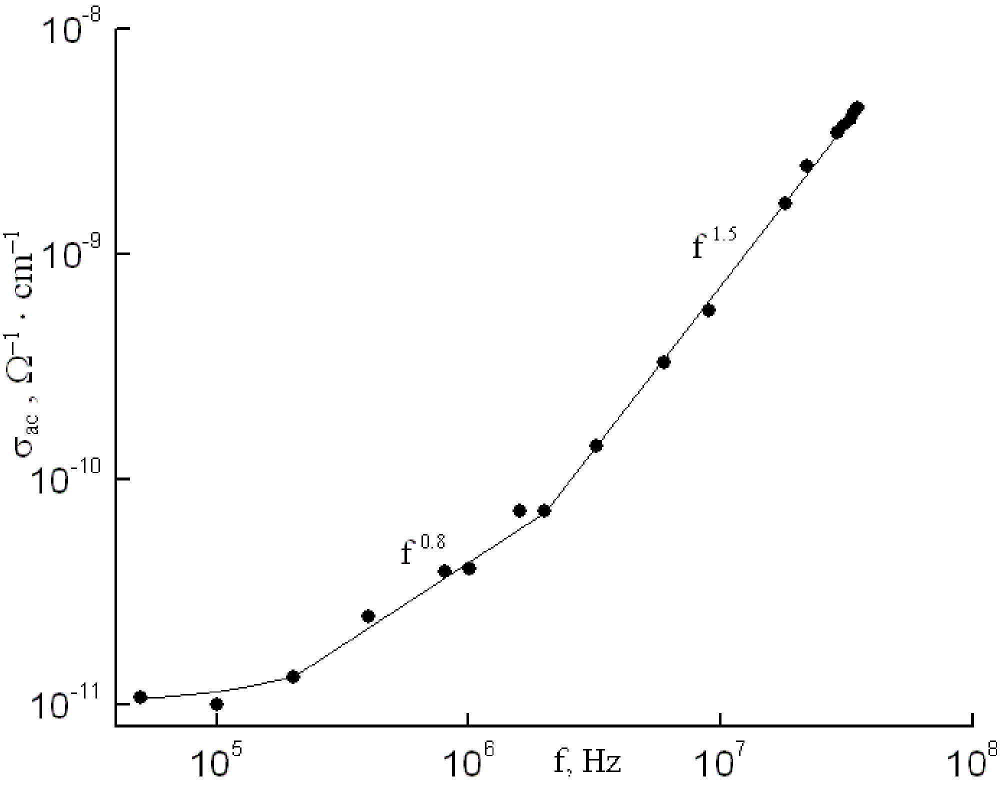

Fig. 3. Frequency-dependent ac conductivity of GaSe amorphous film at room temperature.

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