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ELECTRICAL PROPERTIES OF HYDROGENATED AMORPHOUS $Si_{1-x}Ge_x$ THIN FILMS

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Thin films of hydrogenated amorphous Si-Ge alloys were obtained by r.f. sputtering in Ar + H_2 gas atmosphere using composite targets of Si and Ge. Dark conductivity and photoconductivity were measured in the temperature range of 300–500 K for films with x varying from 0.11 to 0.63. Both dark conductivity and photoconductivity exibit activation type dependences in the temperature range studied. Heterogeneity two-phase model and a model based on Fermi level shift with temperature were invoked to discuss the conduction mechanism.

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Amorphous hydrogenated binary Si-Ge alloy films (a-$Si_{1-x}Ge_x$:H) have recently been investigated extensively and are expected to be a useful optoelectronic material for $\lambda > 700$ nm [1–5]. Introduction of Ge reduces the optical gap below 1.8 eV, typical for a-Si:H and better matches the optical gap for the solar radiation spectrum. It appears, however that alloying Si with Ge leads to a deterioration of photoelectronic properties. Such behaviour is not peculiar to a-$Si_{1-x}Ge_x$:H alloys only. Similar findings have been reported for other alloy systems such as a-$Si_{1-x}C_x$:H [6] and a-$Si_{1-x}Sn_x$:H [7].

Most of Si-Ge alloy films are deposited by the glow discharge decomposition of a gas mixture of SiH_4 and GeH_4 [1–3], [5]. However, this method has several drawbacks such as the poisonous and inflammable nature of the reactive gases and the poor control of the hydrogen content in the film. An alternative method is reactive sputtering [8, 9] of multicomponent target in d.c. or r.f. electric field in an atmosphere of inert gas and H_2.

1. Experimental details

All samples in the form of thin films were obtained by r.f. sputtering in 13.56 MHz diode system. Sputttering atmosphere was a mixture of Ar and H_2 (both of 5N purity) with the partial pressure ratio $p_{H_2}/(p_{H_2} + p_{Ar}) = 0.21$. The Ge composition was varied by changing the number of Ge discs put on 100 mm Si target. The content of germanium in the films was determined by electron microprobe analysis. Further technology conditions are given in Table I.

TABLE I

Deposition parameters and characteristics of investigated samples.

Sample	1SGHN	2SGHN	3SGHN	4SGHN	5SGHN	6SGHN
Substrate temp. (°C)	283	280	280	269	280	261
Discharge power (W)	190	185	185	125	150	155
Ge content x	0.63	0.51	0.47	0.26	0.19	0.11
Sputtering rate(Å/s)	2.8	2.6	2.4	2.3	2.1	2.1

Two coplanar Al stripes evaporated onto the film with the distance of about 0.5 mm served as electrodes. Both dark and photoconductivity were measured in vacuum in the temperature range from room temperature to about 500 K. Ohmic behaviour of contacts was checked up to the applied field of 200V/cm. Tungsten-iodine lamp with ITO filter served to illuminate the film.

2. Results and discussion

Figure 1 shows the inverse temperature dependence of the dark conductivity σ_d for a series of amorphous alloy $Si_{1-x}Ge_x$:H films (the results for other x values are omitted to simplify the figure). It is clear from Fig. 1 that two activation energies exist over the temperature range studied. Decrease in the slope of $\ln\sigma$ vs. $1/T$ at high temperatures ($10^3/T < 2.4$ K^{-1}) have been found by other workers [10]. Assuming the activated-type conduction formula

$$\sigma_d = \sigma_0 \exp(-E_A/kT),$$

it was possible to calculate E_A and σ_0 for both temperature ranges: low temperature (E_{A1}, σ_{01}) and high temperature range (E_{A2}, σ_{02}), see Table II.

TABLE II

Activation energies and pre-exponential factors from the dark conductivity σ_d and photoconductivity σ_{ph} measurements.

Sample	x value	activation energy (eV)			pre-exp. factor $(\Omega\text{cm})^{-1}$		
		E_{A1}	E_{A2}	E_{Aph}	σ_{01}	σ_{02}	σ_{oph}
2SGHN	0.51	0.48	0.31	0.21	35.3	0.79	$1.9\cdot10^3$
4SGHN	0.26	0.70	0.68	0.24	$2.9\cdot10^3$	$1.6\cdot10^3$	$1.9\cdot10^3$
5SGHN	0.19	0.84	0.73	0.30	$1.6\cdot10^6$	$4.2\cdot10^3$	$1.3\cdot10^3$

With the increase of atomic percentage of Ge the dark conductivity increases as a result of the decrease in activation energy and from the variation of pre-exponential factor.

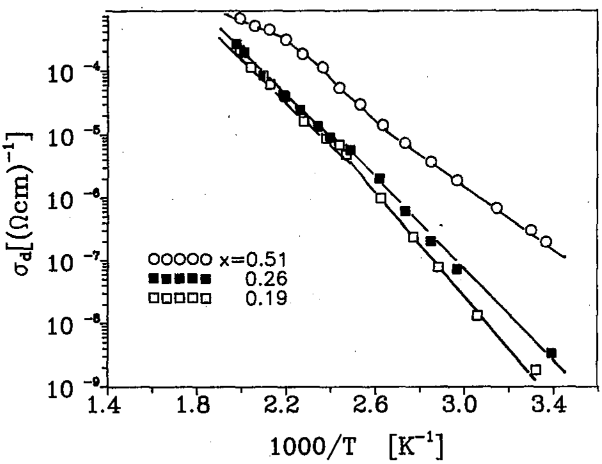

Fig. 1. Dark conductivity vs. $1000/T$ for samples of different germanium concentration x.

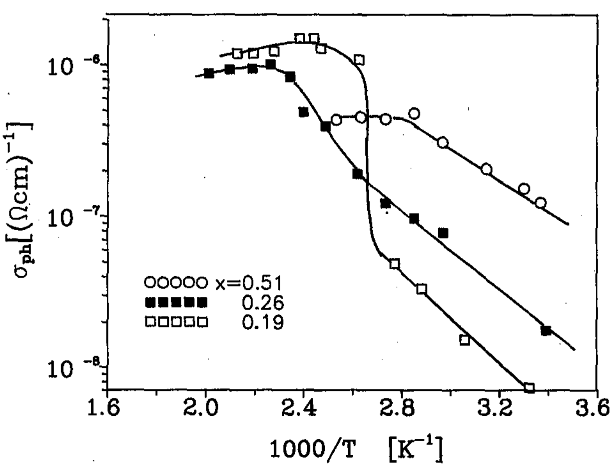

Fig. 2. Photoconductivity vs. $1000/T$ for samples of different germanium concentration x.

In order to explain the existence of two activation energies in the slope of $\ln \sigma$ vs. $1/T$ we can employ Anderson and Paul model of heterogenous film structure [10]. The film is supposed to consist of islands of high atom density and a low atom density tissue. In the islands, most of the dangling bonds are compensated by hydrogen probably in the monohydride Si–H configuration. In the tissue, there is a larger density of defects and a greater variety of Si–H bonding entities. Island and tissue therefore exibit different transport properties. For low temperatures the measured conductivity is determined by island material and at high temperatures by the tissue.

Another possible approach is based on the theory given by Overhof and Beyer [11]. In this case the "kink" on the $\ln\sigma$ vs. $1/T$ curve is produced by a rapid change of the dependence of the Fermi level on temperature near the kink temperature. The rapid change is linked to the occurence of fluctuations in the potential.

Figure 2 shows the temperature dependence of photoconductivity $\sigma_{\mathrm{ph}} = \sigma_{\mathrm{ill}} - \sigma_{\mathrm{d}}$ for the same Ge compositions as in Fig. 1. Calculated parameters E_{Aph} and σ_{oph} for activation type conductivity in the low temperature region are given in Tab. II. In the high temperature region, which coincides with that of Fig. 1, photoconductivity saturates. The absolute values of σ_{ph} for Si-Ge alloys as in Fig. 2 are lower than that for a-Si:H but are still high. For $x > 0.5$ the photoconductive properties of our samples in the high temperature region are lost. Unhydrogenated Si-Ge samples did not exhibit any photocurrent.

In authors opinion more work is needed to explain the temperature variations of photoconductivity in hydrogenated Si-Ge alloys. The most important problem is here evaluation of the influence of hydrogen concentration in the film on the photocurrent response.

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