FIELD — EFFECT MEASUREMENTS IN DOPED HYDROGENATED AMORPHOUS SILICON FILMS

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ABSTRACT — Field-effect measurements were performed at several temperatures in hydrogenated amorphous silicon (a - Si : H) films with different doping concentrations. These films were prepared by sputtering of ions in the liquid phase followed by activated reaction in a plasma of argon and hydrogen [1]. The process of preparation of the samples and the method of measurement are described. It is attempted to correlate the properties of the films with parameters of their preparation. The screening responsible for the field-effect is, at lower temperatures, ascribed to the localized states situated near the Fermi level, whereas at higher temperatures the dominant role is played by the mobile carriers in the extended states. The process of calculation of the field-effect electronic density, N_{FE} [2], is presented; in our samples it falls within the range 10^{16} - 10^{19} cm^{-3} eV^{-1}. The interpretation of the results is assisted by knowledge of the values of the electrical conductivity, which help to understand the mechanisms involved.

1 — INTRODUCTION

Amorphous semiconductors with tetrahedral bonds, as it is the case of the amorphous silicon (a-Si), exhibit a continuous distribution of the electronic states in the forbidden gap, defined between the mobility edges, E_v and E_c, of the valence and conduction bands. Hydrogenated amorphous silicon (a - Si : H) deposited on substrates at a temperature around 250°C, shows, because of a reduction in dangling bonds through liaisons with hydrogen atoms, a low value of the state density in the central region of the forbidden gap. As a consequence [3], it is possible

to dope a - Si : H films, leading that way to type - n or type - p semiconductors.

When a transverse electric field is applied across a dielectric material, the resistance of the sample is changed. The measurement of this change in the resistance of a film, due to the field-effect, has been a method largely used to evaluate the density of states N (E) [4]. In this paper the approach proposed by Mahan and Bube [2] has been admited, by considering a field-effect electronic density, N_{FE} , in order to characterize the distribution of states. Parameters related to the resistivity of the samples are also presented.

It must be said that the measurements have been performed on samples which have been produced using a new method already described [1].

2 — EXPERIMENTAL CONSIDERATIONS

The samples were obtained by sputtering of ions from the liquid phase, followed by an activated reaction taking place in a plasma of argon and hydrogen. The liquid phase was obtained on the top of n - and p - type cylinders of silicon, with different

TABLE

Sample	Ingot ohm-cm /Type	Substrate	Flow rate (cm^3/min)		Deposition Time (min)	Film Thickness (μm)
			H_2	Ar		
RE 12	2 p	Mica	37	30	1.5	0.9
RE 20	.02 p	Glass 7059 + Al + SiO_2 (0.2 μm)	37	30	2.5	1.2
RE 23	10 n	Glass 7059 + Al + SiO_2 (0.1 μm)	36	28	2.5	0.5
RE 35	.02 p	Mica	33	11.5	2.5	0.8
RE 36	.02 p	Mica	30	15.5	2.5	0.7
RE 37	.02 p	Mica	10	35	2.5	0.8
RE 38	.02 p	Mica	6	39	2.5	0.9

concentrations of doping, by means of the bombardment of a focused beam of 8.2 keV electrons, the beam power being 1.6 kW. The substrate, connected to earth, was maintained during growing at a temperature of 250°C. The pressure in the reaction chamber was initially less than 10^{-5} Torr, taking during deposition a value of 3 mbar (except for sample RE37 in which the value was 1 mbar). In the Table, further characteristics of the measured samples are given.

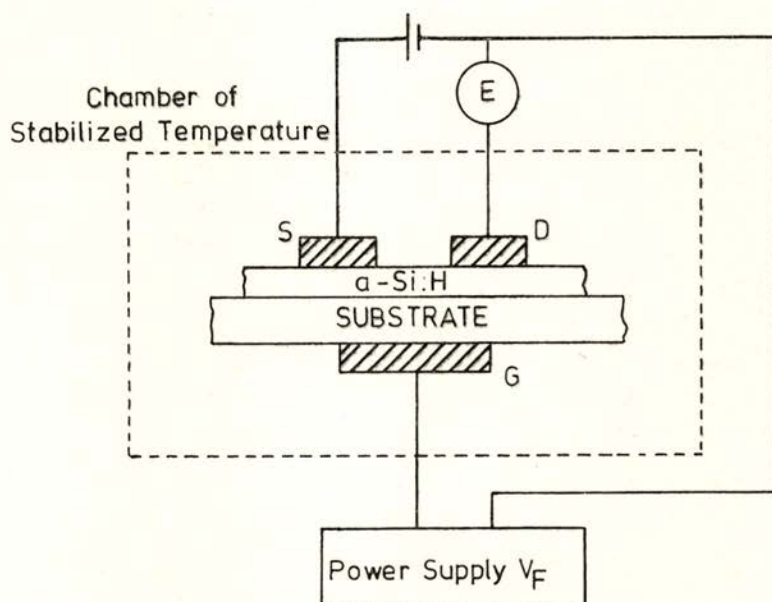

Fig. 1 — Experimental set-up for measurement of the field-effect (schematic).

The dielectric layer of SiO_2 was processed by the same method as described for the a - Si : H film; in the chamber a mixture of argon and oxygen gases was used, the time of deposition being 2.5 minutes. Aluminium contacts were used with the type - p specimens but with the RE23 sample, of type - n, the contacts were made of superposed layers of antimonium and gold.

Figure 1 represents the set-up used to perform the field-effect measurements. The substrate plays the role of insulating dielectric

in the conventional IGFET geometry, the distance between the source S and the drain D being of the order of 100 μm. A field voltage V_F, varying between -100 and $+100$ V, is applied to the field electrode, the gate G. A variable channel voltage, V_c, is used between the source and the drain, and the corresponding current is measured by an electrometer (Keithley 614 Electrometer).

The thickness of the films was measured with a Talysurf.

3 — RESULTS AND COMMENTS

The transverse electric field imposed across the film and the dielectric substrate creates a space charge layer near the film – substrate interface which commands the resistance of the film. Since this space charge resides predominantly in localized gap states, the field-effect provides information about the corresponding density of states.

For different temperatures, with a constant channel voltage V_c, values of the source-drain current, I_{SD}, were obtained as a function of the gate voltage, V_F (field voltage). Being I_o the value of the current I_{SD} for $V_F = 0$, we can write

$$V_c = R_o \, I_o$$

When $V_F \neq 0$ we have

$$V_c = (R_o + \Delta R) \; I_{SD}$$

and therefore

$$\Delta R / R = (I_o / I_{SD}) - 1$$

Plotting $\Delta R / R$ in terms of V_F (as an example, see Figure 2), we can easily evaluate $R / (dR / dV_F)$ for $V_F = 0$, which is simply the inverse of the slope at the origin for each one of the curves. This parameter is fundamental for the kind of presentation and analysis of the results here exposed. The resistance change is due to band bending created by the spatial charge which screens the external electrical field.

It is appropriate to consider a quantity N_{FE}, called the field-effect state density and given, for the case of small changes in resistance, by

$$N_{FE} = (R/(dR/dV_F))_0 \cdot \varepsilon_d/(e\,d\,D\,k\,T)$$

where ε_d is the dielectric constant of the dielectric material used, e is the electronic charge, d is the thickness of the dielectric

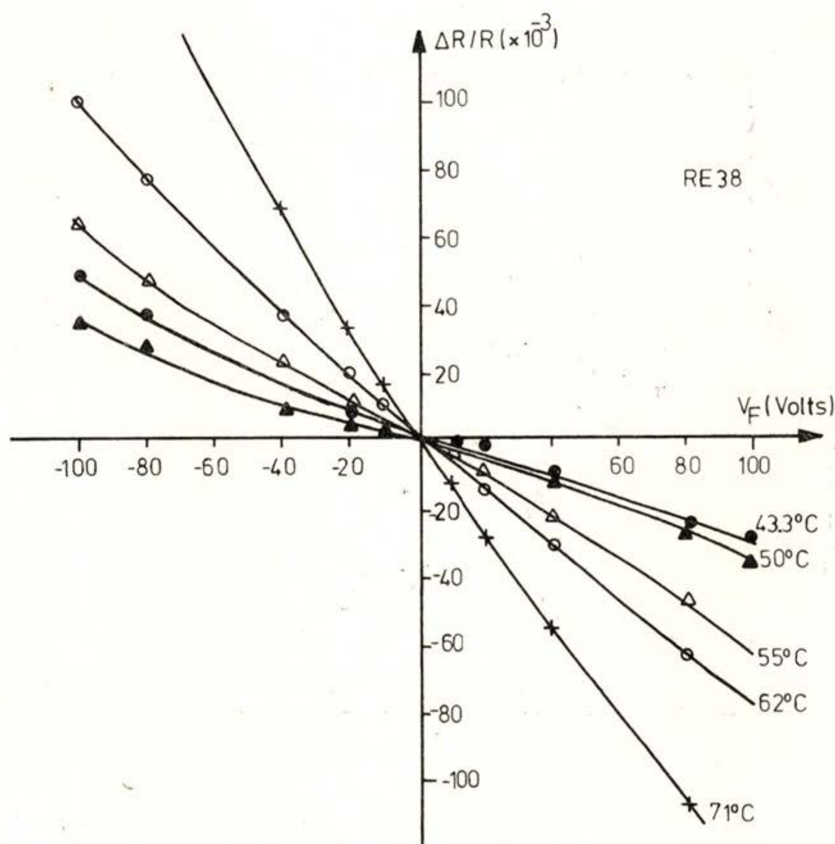

Fig. 2 — ΔR/R as a function of V_F for the sample RE 38.

material, D is the thickness of the amorphous film, k is the Boltzmann constant, T is the absolute temperature and

$(R / (dR / dV_F))_0$ has the meaning referred above. In principle, a temperature independent N_{FE} means that the screening is provided by localized states situated near the Fermi level. In case of N_{FE} being thermally activated, the corresponding thermal activation energy corresponds to the energy difference between the level of screening and the Fermi level.

The results obtained with the samples RE12, RE20, RE23, RE35, RE36, RE37 and RE38 are shown in Figure 3. The observed

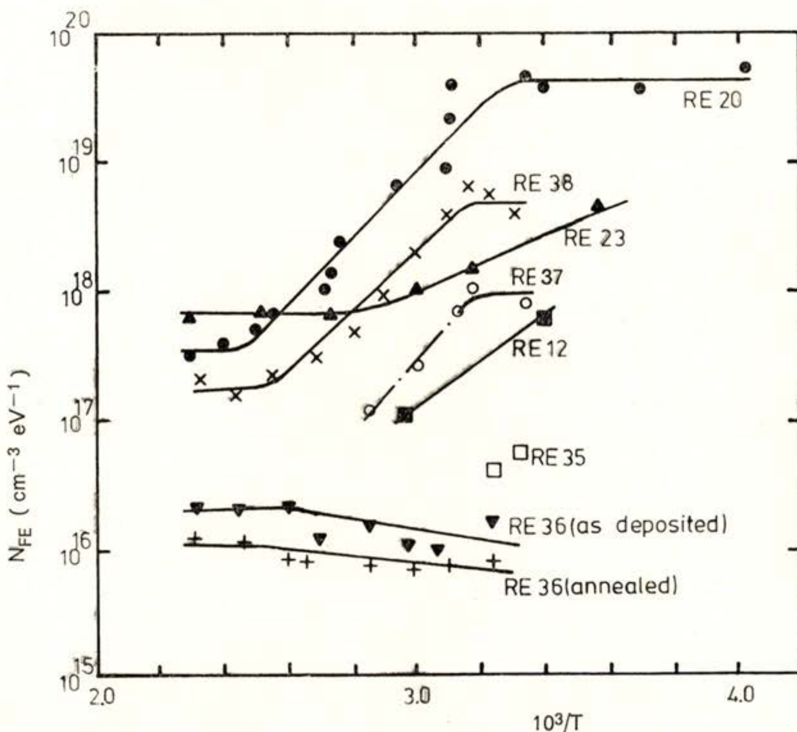

Fig. 3 — Field-effect state density as a function of the inverse temperature for samples RE 12, RE 20, RE 23, RE 35, RE 36, RE 37 and RE 38.

density of states varies within the range 16^{16} - 10^{19} cm^{-3} eV^{-1}, which shows agreement with figures obtained by other authors [5, 6] in samples produced by glow discharge. However, the general features of these curves do not show similarity with

those referred in the literature. As a matter of fact, in our samples the density of carriers N_{FE}, responsible for the screening, not only decreases with temperature but also shows a tendency to level-off at high values of temperature. This behaviour is rather odd and appears to be in disagreement with the thermal variation of the electrical conductivity measured in the same specimens, as can be seen in Figure 4.

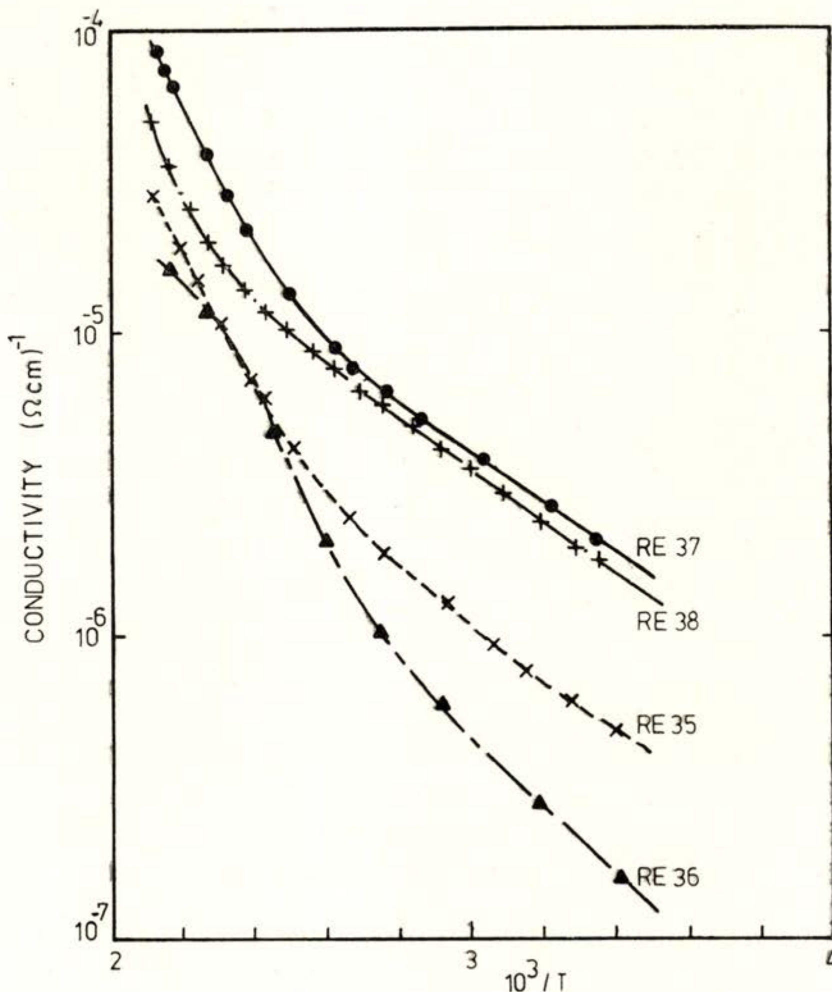

Fig. 4 — Electrical conductivity as a function of temperature for samples RE 35, RE 36, RE 37 and RE 38.

It could be thought that incorrections or deficiencies in the experimental set-up were the cause of these discrepancies. However, it is difficult to accept this sort of explanation, since the results obtained with several samples in different conditions exhibit, besides reproducibility, a pattern of reasonable global coherence. Can it be the case that phenomena of recombination take place in these doped samples under stationary conditions of the field voltage, the rate of which increases with temperature? Another possible interpretation for the source of the observed behaviour can be found in the fact that the field-effect current is usually confined inside a narrow channel, 20-100 Å thick, under a strong accumulation of charge carriers [7]. The surface, both in the immediate vicinity of the substrate and in the first deposited layers, will present electronic states which are mainly responsible for the screening of the electrostatic field. That would explain the different observed thermal behaviour of the electrical conductivity which is essentially dependent on the bulk electronic states.

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REFERENCES

[1] J. C. ANDERSON, S. BISWAS and C. S. FURTADO, Preparation of Amorphous, Si : H, IX International Vacuum Congress, Madrid (1983).

[2] J. E. MAHAN and R. H. BUBE, *J. Non-Cryst. Solids*, **24**, 29 (1977).

[3] W. E. SPEAR and P. G. LE COMBER, *Phil. Mag.*, **33**, 935 (1976).

[4] M. J. POWELL, *Phil. Mag.* **B43**, 93 (1981).

[5] ZIMMER S. JAN and RICHARD H. BUBE, *J. Electron. Mat.*, **8**, 47 (1979).

[6] NANCY B. GOODMAN, *Phil. Mag.*, **B45**, 407 (1982).

[7] N. B. GOODMAN and H. FRITZSCHE, *Phil. Mag.*, **B42**, 149 (1980).