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PHOTOCONDUCTIVITY IN a-Si:H AND a-Si<sub>x</sub>C<sub>1-x</sub>:H, CORRELATION WITH  
PHOTOLUMINESCENCE RESULTS

D. Caffier, M. Le Contellec and J. Richard

CNET, Centre Lannion B, ROC/TIC, 22301 Lannion, France

Abstract.- Photoconductivity and photoluminescence of a-Si : H and a-Si<sub>x</sub>C<sub>1-x</sub> : H films prepared by glow discharge or R.F sputtering have been studied. For a-Si : H sputtered films, the photoconductivity is greatly increased with R.F power, substrate temperature and can be compared to values obtained for glow discharge films. The addition of a low carbon content (< 10 %) does not affect the photoconductivity but a higher content greatly decreases it. In conclusion, we deduced that the existence of a high 1.2 eV photoluminescence peak is a necessary condition to obtain a good photoconductivity.

Introduction.- Many works have been made on photoconductivity [1] and photoluminescence [2] of a-Si : H films prepared by glow discharge or R.F sputtering. In this paper, we present an assumption on the structure of our a-Si : H sputtered films which will be developed in a futur work. This assumption is related to the results obtained by photoconductivity and photoluminescence measurements. We also present preliminary results of photoconductivity in a-Si<sub>x</sub>C<sub>1-x</sub> : H.

Samples preparation.- The a-Si : H and a-Si<sub>x</sub>C<sub>1-x</sub> : H films were respectively prepared by two methods : decomposition of silane or silane + methane [3] in a glow discharge, R.F sputtering of a silicon target in an Argon + hydrogen or Argon + hydrogen + methane [4] atmosphere. All these films have a high hydrogen content (> 10 %). For some experiments, we have used a-Si : H films prepared by decomposition of silane at a substrate temperature of 500°C and post hydrogenated. After post-hydrogenation the film contains a low hydrogen content below 1 %.

Experimental results :

1°) Photoconductivity results :

The variation of photoconductivity  $\Delta\sigma$  ( $\Omega^{-1}\text{cm}^{-1}$ ) versus photon energy for a  $10^{15}$   $\text{ph cm}^{-2}\text{s}^{-1}$  photons flux has been measured in a-Si : H and a-Si<sub>x</sub>C<sub>1-x</sub> : H films (fig. 1).  $\Delta\sigma$  is the difference between illuminated and dark conductivities. The photo-current  $I_p$  is given by :

$$I_p = I \left( \frac{10^{15}}{F} \right)^\beta$$

I and F are respectively the current under illumination and the photons flux. The exponent  $\beta$  is given by the variation of I versus photons flux for a fixed energy.

For a-Si : H sputtered films,  $\Delta\sigma$  has been determined as a function of R.F power, partial hydrogen pressure, substrate temperature  $T_s$  and annealing temperature. The photoconductivity increases with R.F power ; but for a low power, we obtain also a high  $\Delta\sigma$  after annealing at 300°C or by increasing the substrate temperature during deposition (fig. 2). In this last case,  $\Delta\sigma_{\text{max}}$  (maximum of  $\Delta\sigma$ ) has a value similar to

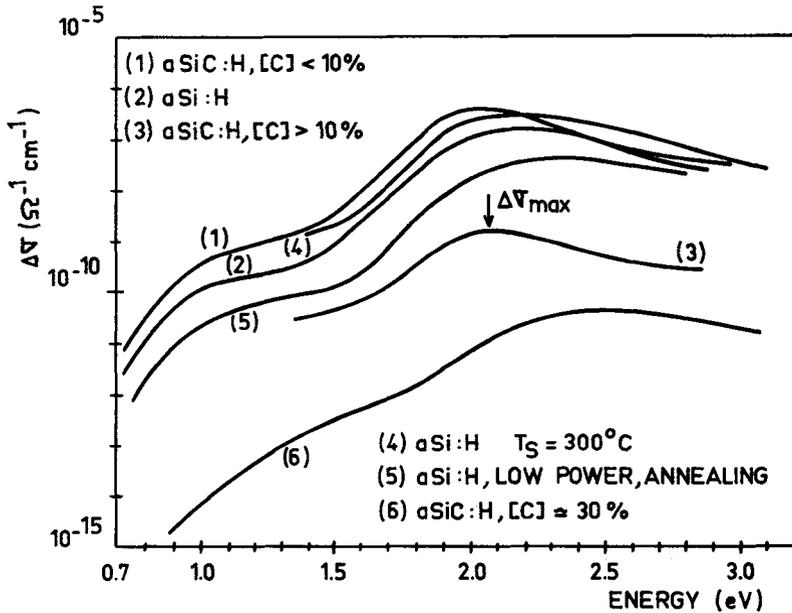


Fig. 1 : Photoconductivity versus photon energy  
 (1), (2), (3) : Glow discharge films  
 (4), (5), (6) : R.F sputtering films

than obtained in glow discharge samples ( $\approx 10^{-7} \Omega^{-1} \text{ cm}^{-1}$ ).

For  $\text{a-Si}_x\text{C}_{1-x}:\text{H}$  films,  $\Delta\sigma_{\text{max}}$  can be higher than for  $\text{a-Si}:\text{H}$  films prepared in the same conditions if the carbon concentration does not exceed about 10 % (fig. 1, sample n° 1). Beyond this concentration,  $\Delta\sigma_{\text{max}}$  greatly decreases due to an important defects density which have been measured by electron spin resonance ( $10^{18} \text{ cm}^{-3}$ ) [5].

The following features are of interest :

(I)  $\Delta\sigma$  exhibits a maximum value,  $\Delta\sigma_{\text{max}}$ , at an energy which increases with hydrogen or carbon content. The energy of this maximum is related to the optical gap.

(II) All the curves of  $\text{a-Si}:\text{H}$  films show a shoulder between 1 eV and 1.3 eV followed by a rapid rise above about 1.5 eV. This feature appears to be closely similar to those of absorption curve. This shoulder suggests a local density of state maximum near 1.2 eV [6].

(III) Below the shoulder the photoconductivity greatly decreases and disappears at 0.7 eV.

(IV) For  $\text{a-Si}_x\text{C}_{1-x}:\text{H}$ , when the carbon concentration is low, the shoulder at 1.2 eV exists. So we suggest, in correlation with photoluminescence results [5], that amorphous silicon carbide contains some silicon clusters large enough to produce the typical photoconductivity of amorphous silicon. But, when the concentration increases, this shoulder disappears and  $\Delta\sigma_{\text{max}}$  is located at higher energies.

2°) Photoluminescence  
results :

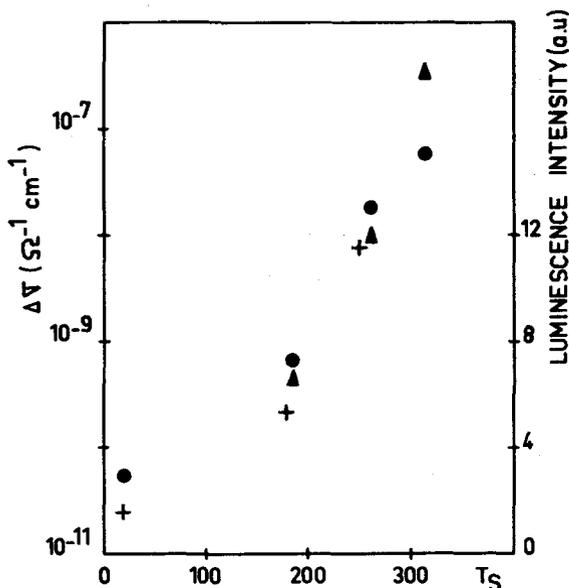


Fig. 2 : ● ▲ Photoconductivity versus substrate temperature for two sputtered a-Si : H samples  
+ 1.2 eV luminescence peak Intensity versus substrate temperature

The luminescence measurements were performed on samples held at 4.2°K under Argon laser excitation at 2.6 eV. For these measurements, the films were deposited on frost substrates to remove interference effects. The detection was made either by a photomultiplier or by a cooled lead sulphide cell. The luminescence was corrected for the response of the detector system, which was determined using a Tungsten lamp of measured color temperature. Fig. 3 shows luminescence spectra for samples prepared at two different substrate temperatures. After deconvolution, we observe generally in our spectra three peaks : a peak at a fixed energy of 1.2 eV and two other peaks whose energy varies, one between 1.02 eV and 1.1 eV and the other one between 1.33 eV and 1.4 eV. From fig. 2 and fig. 3, we deduce that the photoconductivity increases as the photoluminescence intensity, specially as the intensity of the 1.2 eV peak. For a-Si<sub>x</sub>C<sub>1-x</sub> : H films, as  $\Delta\sigma_{\max}$ , the photoluminescence intensity decrease with the carbon concentration [5].

Interpretation. - To determine the origin of the 1.2 eV peak, we have prepared a-Si film by decomposition of silane at substrate temperature  $T_s$  of 500°C. As prepared the film does not contain hydrogen and photoconductivity is not measurable, but reaches a great value ( $10^{-6}\Omega^{-1}\text{cm}^{-1}$ ) after post-hydrogenation. Without hydrogen, pure a-Si contains about  $5 \cdot 10^{19} \text{cm}^{-3}$  paramagnetic centers [7]. Post-hydrogenation introduces in the film a hydrogen concentration large enough to eliminate completely the dangling bond E.S.R. Signal ( $< 10^{17} \text{cm}^{-3}$ ) [7].

For this film and only after post-hydrogenation, we observe a high photoluminescence located at 1.2 eV. From this and results before, we conclude :

(I) the existence of 1.2 eV peak is a necessary condition to obtain photoconductivity.

(II) A high  $\Delta\sigma_{\max}$  is related to a high intensity of this peak.

In all our sputtered films we observe always a 1.2 eV photoluminescence peak and also other peaks whose energy depends on preparation conditions. It seems that the peak at 1.2 eV is a characteristic of an amorphous silicon with a low gap state density. So we assume that our films are composed of two materials type of clusters.

- a-Si : H clusters with a high hydrogen content, a large gap ( $> 1.5 \text{ eV}$ ) and many defects. The hydrogen is not just saturating dangling bonds but it modifies the

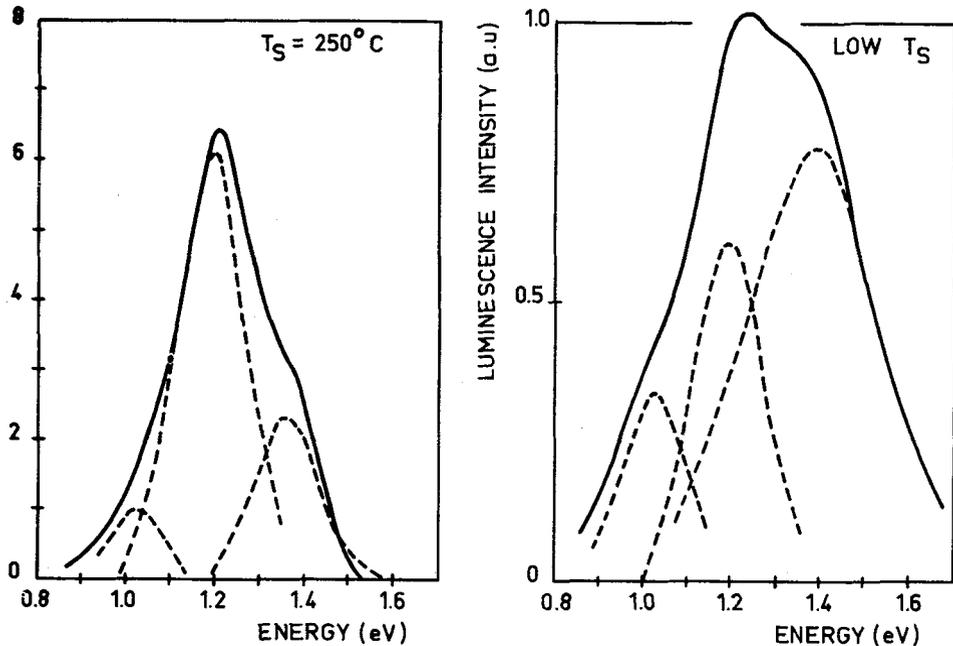


Fig. 3 : Luminescence spectra of a sputtered a-Si : H for two substrate temperatures

whole structure [8]. Knight [9] shows that the total hydrogen content does not correlate with the defect density and as the hydrogen concentration is increased in certain ways there is a rapid rise in the spin density.

- a-Si : H clusters with a very low hydrogen content, but large enough to compensate the defects (low spin density), and a small gap ( $\approx 1.37$  eV). This a-Si : H can be compared with the post-hydrogenated a-Si.

Conclusion.- Sputtered a-Si : H films photoconductivity can be compared to values obtained for glow discharge films. The addition of carbon (< 10 %) does not affect the photoconductivity value, but a higher content greatly decreases it. From correlation with photoluminescence results we conclude that a high 1.2 eV peak is a necessary condition to obtain photoconductivity. Our sputtered films can be considered as a-Si : H films composed of amorphous silicon clusters with, respectively, a high hydrogen content and a very low hydrogen content.

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