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# Transport and Recombination Properties of Amorphous Silicon Films

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**〈Abstract〉**

Drift mobility, conductivity, and intensity-dependent photoconductivity measurements were made on three a-Si films prepared differently by dc glow discharge decomposition of silane. The results suggested that the recombination of undoped samples takes place mainly between electrons in tail states and holes in defect states, while that of a P-doped sample whose transport is interpreted as phonon-assisted hopping in the donor band occurs between electrons in the donor band and holes in defect states.

# 비정질 규소 박막의 전자수송 및 재결합 특성

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**〈요 약〉**

사일렌 기체를 글로우 방전으로 분해시켜 제작한 비정질 규소 박막들의 전류 이동도 및 전기 전도도, 그리고 광전기전도도를 측정하였다. 그 결과, doping 되지 않은 시료의 경우엔 trap의 전자와 defect state의 양공이 주로 재결합하나, 인(phosphorus)이 doping 된 시료의 경우엔 대부분의 전기전도는 donor band에서의 electron hopping에 의해 이루어지며 그 donor band의 전자와 defect state의 양공간의 재결합이 이루어짐을 알 수 있었다.

## I. Introduction

The extensive works on amorphous silicon and germanium have shown that the electronic properties of this non-crystalline solids depend critically on the methods of preparation and on the detailed conditions of the specimen deposition. For instance, hydrogenated amorphous films(a-Si: H) prepaerd by the glow discharge method (decomposition of silane gas in a glow discharge) may well differ in its electrical conductivity according to deposition rate and substrate temperature, etc.[1] These effects, which are known to be due to the defect structure that is extremely sensitive to preparation conditions and has a great influence on the electronic properties, have been serious obstacles in understanding the amorphous tetrahe dral solids.[2],[3]

Recently, a large number of experiments revealed step by step the distribution of the electronic states and transport properties in disordered structures. In the following are

reported the experiments on the temperature dependence of drift mobility of a-Si : H specimens prepared in different methods which in conjunction with that of conductivity, helps to determine the transport properties and the recombination processes of a-Si : H. The advantage of this experiment is that one can distinguish changes in the equilibrium fermi level(which affects conductivity) from changes in the density of states and mobility of band and trapping centers which affect drift mobility. [4]

## Ⅱ. Experimental Details

### 1. Sample Preparations

Three samples were prepared using two dc discharge systems of which schematic diagrams are shown in Fig. 1. In these systems, plasma was produced by dc 730 V power supply through two disk electrodes separated by 5cm. Pressure and gas flow rate were kept 0.8 torr and 5 sccm and substrate temperature was maintained to be 310 C by a heater. 4-electrodes method and screened cathode method were employed to produce different samples. Sample A and B were deposited in 4-electrodes method and screened cathode method each. Sample C was prepared using 4-electrodes method with doping of $PH_3$ of 200 v. p. p. m.

### 2. Experimental Procedure

A schematic diagram of experimental configuration of the response time method to obtain drift mobility is shown in Fig. 2. [5] A prepared a-Si film, on which aluminium electrodes were coated wth a separation of 0.1 mm, was fixed on a copper rod in the cryostat and series connection was made to dc power supply and a variable resistance, of which two ends were connected to oscilloscope (Tektronix 7603). The signal on the oscilloscope screen was photographed by a camera equipped with a macro-lens when light pulses were illuminated onto the sample. He-Ne laser ($\lambda$=6328 Å; 1.98 eV) was used as a light source and the light was chopped by light chopper (P. A. R. model 125A) and the rise and fall time of this light pulse was made be smaller than 1 msec.

The response time $\tau_r$ and steady-state photocon-ductivity, $\sigma_{ph}$ was measured from the signal and drift mobility $\mu_d$ was calculated from the

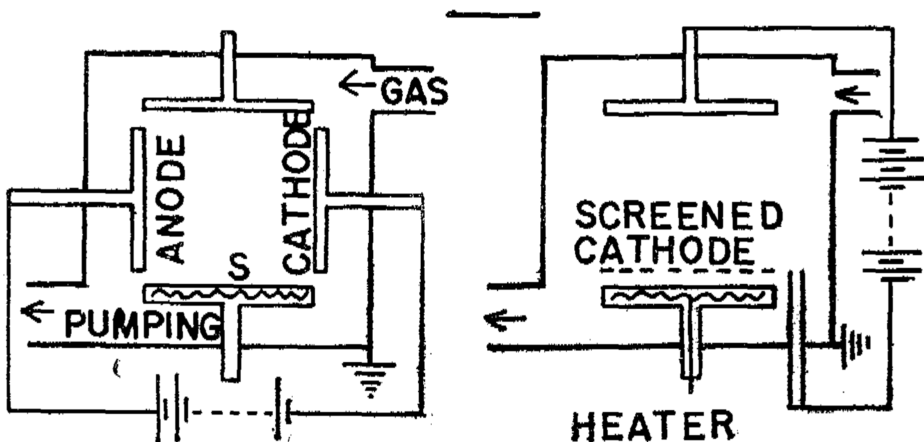


Fig. 1.
Left: The schematic diagram of the reactor used in the preparation of a-Si films by 4-electrodes method.
Right; The schematic diagram of the reactor used in the preparation of a-Si films by screened cathode method.

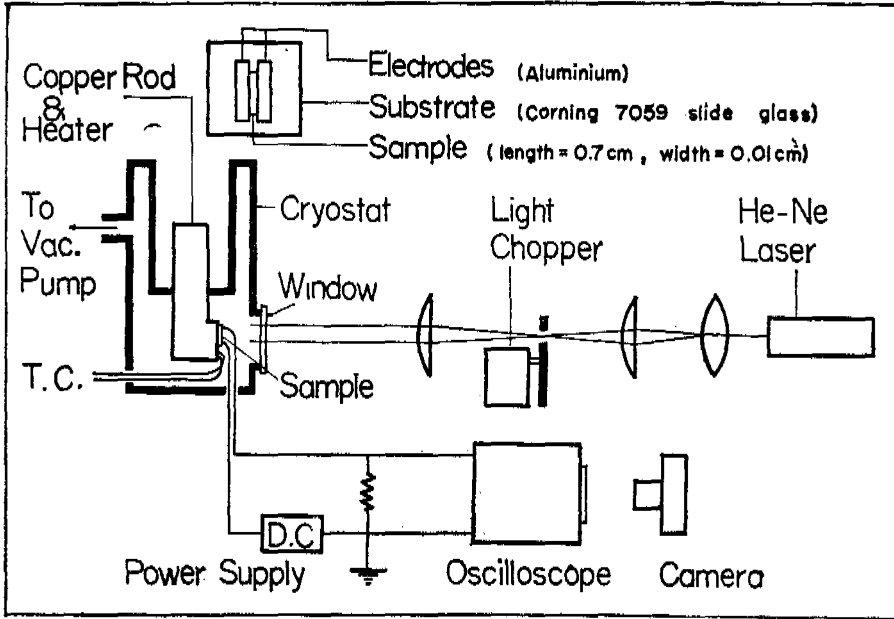


**Fig. 2. Schematic diagram of experimental apparatus and electrode gometry**

following relation,

$$\sigma_{ph}=eG\tau_r\mu_d$$

where the generation rate, $G$ is given by

$$G=\eta I(I-R)(1-\exp(-Kd))/d$$

with
- $\eta$: quantum efficiency
- $I$: incident photon flux
- $R$: reflectivity
- $K$: absorption coefficient
- $d$: thickness of the sample

The (dark) conductivity was measured directly using electrometer (Keithley 616). Additionally photoconductivity versus light intensity was investigated using optical filters and electrometer.

## Ⅲ. Results and Discussion

The temperature dependence of conductivity of undoped samples (A and B) is shown in Fig. 3a, in which the activation energies of sample A and B are 0.73 eV and 0.77 eV, from that we can tell that the fermi energy energy levels are located at 0.73 eV and 0.77 eV each below the mobility edge since the dominant transport mechanism of an undoped sample is extended states conduction in this temperature range ($T>300K$), that is,[6],[7]

$$\sigma=\sigma_1\exp(-(E_c-E_f)_0/kT)$$

($E_c$: energy level of mobility edge
$E_f$: fermi energy level)

Fig. 3b tells us that the activation energy of the sample $C$ is 0.21 eV, which is equal to $E_d-E_f+W$ since the dominant transport mechanism is strongly suggested to be phonon-assisted hopping between the states lying in donor band, that is,[8]

$$\sigma=\sigma_2\exp(-(E_d-E_f+W)/kT) \text{ when } T>400K$$

($E_d$: energy level of donor band
$W$: hopping energy)

As for the results of photoconductivity versus light intensity ($\sigma_{ph}\infty I^{\beta}$), that helps the understanding of recombination behaviour, the exponents of sample $A, B,$ and $C$ was 0.7, 0.6, and 0.5. This result suggest that sample $C$, the doped one exhibits bimolecular recombination behaviour,[9] while partial monomolecular

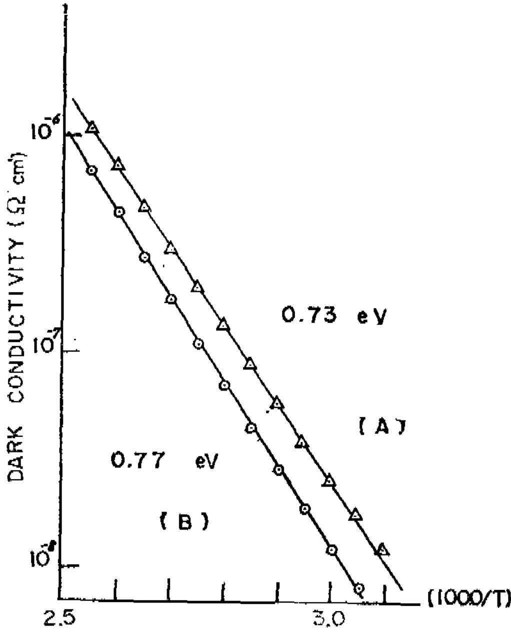


Fig. 3a. Conductivity of sample A and B

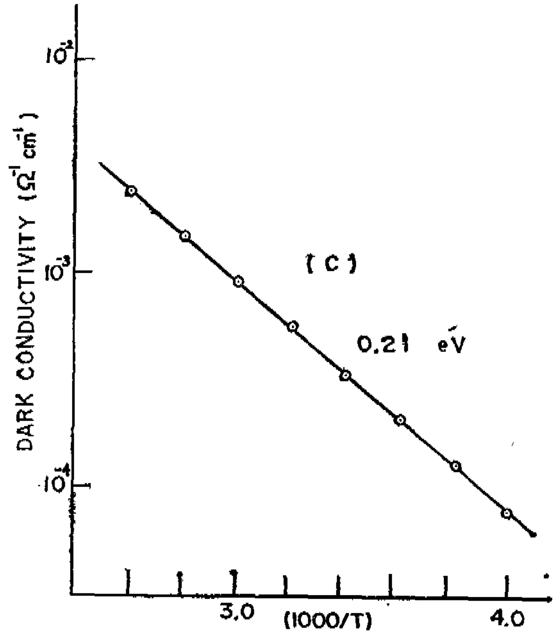


Fig. 3b. Conductivity of sample C

recombinations are seen in sample *A* and *B*.

Drift mobility with photoconductivity of sample *A* and *B* is shown in Fig. 4, 5. The common feature of them is that the activation energies of drift mobility are approximately the same as those of photoconductivity for

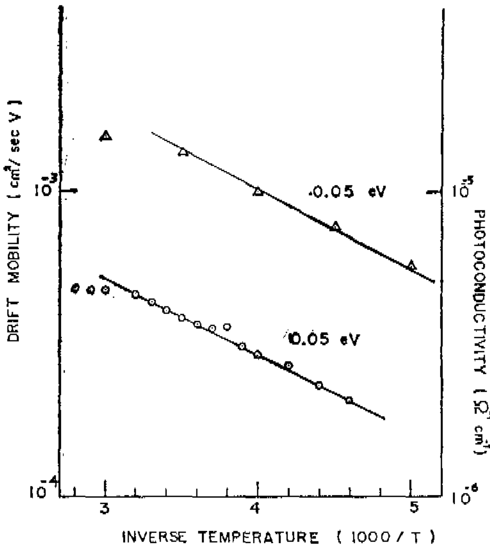


Fig. 4. Drift mobility and photoconductivity of an undoped sample A

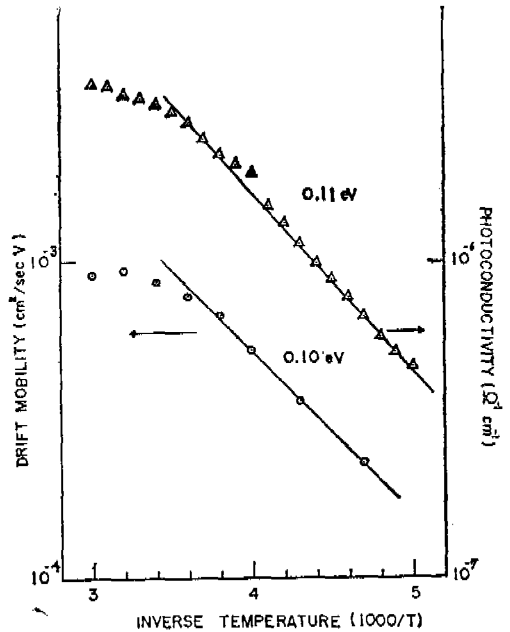


Fig. 5. Drift mobility and photoconductivity of an undoped sample B

each sample. (This is in agreement with that found by Spear et al. except for the kink at

$T=250K$).[4] This result implies that $E_a-E_y$ recombinations take place, (not $E_c-E_y$) that is, recombinatios occur between the localized states in band tail and those in donor-like band arising from defect centers. The reason is as follows:[10] If we make an assumption of $E_c-E_y$ recombination, we can write

$$G=K_1 n_c P_y \qquad (1)$$

From Boltzmann statistics,

$$n_c/n_a=(N_C/N_a)\exp(-(E_c-E_a)/kT) \qquad (2)$$

Since quasi-fermi levels are moved to $E_a$ and $E_y$,

$$n_a=P_y \text{ (when } \sigma_{ph}>\sigma) \qquad (3)$$

Substituting (1), (2), (3) into following equation

$$\sigma_{ph}=n_c e \mu_c \qquad (4)$$

we obtain

$$\sigma_{ph}\propto\exp(-E_c-E_a)/2kT)$$

which is in disagreement with the result.

But if we assume $E_a-E_y$ recombination, then

$$G=K_2 n_a P_y$$

This relation with (2), (3), (4) results in

$$\sigma_{ph}\propto\exp(-E_c-E_a)/kT)$$

which is consistent with the result.

- $\sigma_{ph}$: photoconductivity
- $E_a$: energy level of conduction band edge
- $E_y$: energy level of donor-like band arising from defect centers
- $N_c, N_a$: density of states at $E_c$, $E_a$
- $n_C, n_a$: number density of electrons at $E_C$, $E_a$
- $P_y$: number density of holes at $E_y$
- $G$: generation rate of photo-induced electron-hole pair
- $K_1, K_2$: recombination constants
- $\mu_c$: mobility of electrons at $E_c$

Therefore, $E_a$ of sample $A$ and $B$ are located at about 0.05 and 0.10 eV each below $E_c$. But a part of recombinations of sample $A$ is considered to occur via localized states near $E_f$ as is seen from its partial monomolecular behaviour.[11]

One thing notable is the fact that the values of drift mobility are small compared with those reported by others. This might be explained by the following reasoning: The response time method used in this experiment to obtain drift mobility is different from the time-of-flight method employed by others in that the duration of light pulses is 6msec, much longer than 10 nsec of time-of-flight method. This light pulse is sufficient to establish a steady state in which many photo-induced electrons are distributed along the tail states around $E_a$(which act as traps) to be in equilibrium with extended states, that results in larger thermal release, so that this large thermal release makes reponse time longer and drift mobility smaller than that of the time-of-flight technique.

As for doped sample $C$, the drift mobility is thermally activated with an energy 0.10 eV as shown in Fig. 6. The transport mechanism

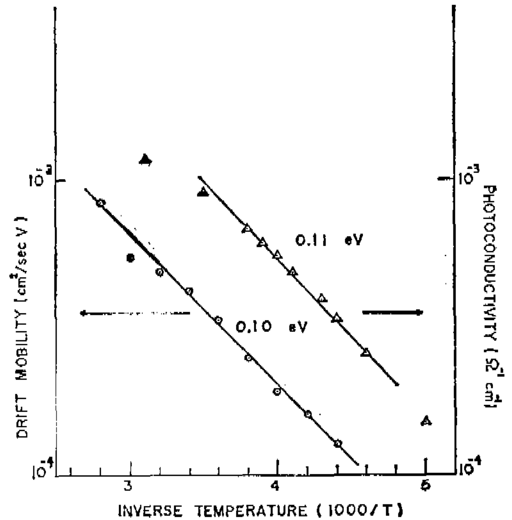


**Fig. 6. Drift mobility and photoconductivity of a P-doped sample C**

of it is considered to be donor band hopping that is partially supported by a large response time(5750 $\mu$sec at $T=330K$).[12] In this interpretation, with the observed bimolecular behaviour the activation energy is the hopping energy, $W$, from which $E_d-E_f$ can be determined to be 0.11 eV, that is, the energy level of donor band in the doped sample is

located at about 0.11 eV above the *fermi* level.

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