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Vacuum Cryostat's Pressure Dependent Dark Conductivity Measurements on a-Si:H and a-SiN:H Films

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Abstract

The electrical properties of $a-Si{:}H$ and $a-SiN{:}H$ films prepared by plasma deposition from $SiH_4 + NH_3$ gas mixtures have been investigated. We observed anomalous peaks in the temperature dependent dark conductivity curves of annealed $a-Si{:}H$ and $a-SiN{:}H$ samples when the temperatures were increased from 90 K to room temperature at a constant heating rate. To study the surface adsorption effect, vacuum cryostat pressure dependence of these peaks are investigated. We have also studied the effect of nitrogen on these observed peaks in dark conductivity.

Key Words: A. Dark conductivity; B. Cryostat pressure; C. Surface effect

1. Introduction

Silicon nitride plays a variedly of important roles in microelectronics devices. Silicon nitride thin films are used in gate dielectric thin film transistors, metal/oxide/nitride/silicon non volatile memories, metal/insulator/semiconductor solar cells, flat screen displays, printers and sensors.

The electronic and optical properties of silicon nitride thin films are strongly dependent on the preparation conditions such as mole fraction ratio, substrate temperature, rf power etc. In addition, the electronic properties of silicon nitride are dominated by deep-charge trapping centres and surface trapping centres. Surface trapping centres are influenced by the cryostat pressure. In this paper we present the results of the cryostat pressure dependence on the dark conductivity measurements when the sample is warmed up from 90 K to 420 K.

2. Experimental Details

The samples were prepared in on rf glow-discharge apparatus, using $SiH_4 + NH_3$ gas mixtures. Corning 7059 glass was used as substrates. The substrate temperature was kept constant at 300 °C, the rf power was held at 5 W, and the total gas pressure was fixed at 200 mTorr. Nitrogen content in the samples has been obtained from the relative partial pressure of NH_3 and SiH_4 gases in the glow-discharge system, defined by the following ratio;

$$r = \frac{[P_{NH_3}]}{[P_{NH_3}] + [P_{SiH_4}]}.$$

Evaporated Al electrodes, separated by 100 μm were used for conductivity measurements. The current was measured with a Keithley 619 Electrometer, with an applied electric field of 10^3 V/cm. Dark conductivity was measured as a function of temperature at two vacuum cryostat pressures (10^{-3} and $6\text{x}10^{-4}$ Torr). Before conductivity measurements, the samples were annealed at 420K for 60 minutes in dark to remove the additional surface adsorbates.

3. Results and Discussion

Figure 1 shows the measured dark conductivities after annealing and during cooling from 420 K to 90 K and heating from 90 K to 420 K with constant cooling and heating rate (4 K/min.) at cryostat pressure of 10^{-3} Torr, for seven $a - SiN{:}H$ samples with $0 \leq r \leq 0.9$. During cooling down, the dark conductivity decreases exponentially at high temperatures and saturates at low temperatures. On the other hand, while heating these annealed samples, starting from liquid nitrogen temperature, a broad peak is observed in the dark conductivity curves between 140 K and 270 K. It seems that, this broad peak is the combination of two peaks one at 210 K and the other at 235 K. This behaviour is very similar for both pure and nitride doped samples. As shown in Figure 2, the peaks appear approximately at the same temperature range for all samples. When the pressure is decreased and if the samples are heated from 90 K to 420 K at $6\text{x}10^{-4}$ Torr, the same behaviour was observed with lower peak amplitudes. As seen in Figure 3, for the cryostat pressure of $6\text{x}10^{-4}$ Torr, the peaks are just observable and at even lower cryostat pressures they all disappear: at cryostat pressures less than $6\text{x}10^{-4}$ Torr, the dark conductivity measurements (Figure 4) are identical for cooling and heating cycles.

For pure and nitrogen-alloyed samples the dark conductivity values at 235 K and at 400 K are given in Table 1, both during cooling and heating up. As can be seen from the table, dark conductivity values in warming up are greater by two orders of magnitude than the values obtained during cooling down at temperatures where the peaks appear.

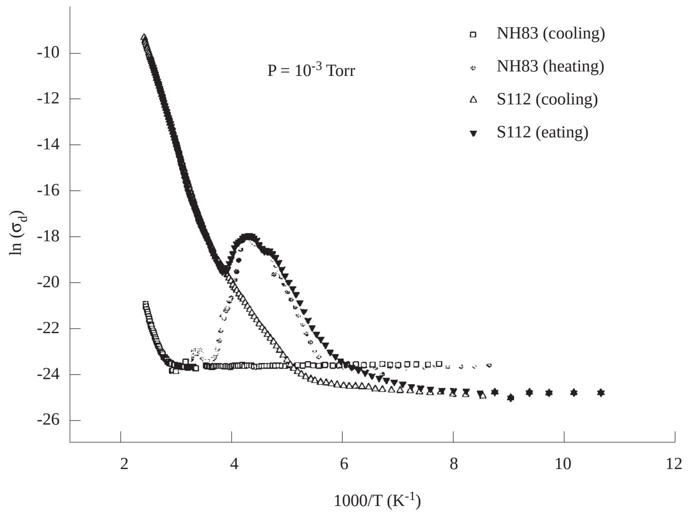

Figure 1. Dark conductivities measured, after annealing, during cooling from 420 K to 90 K and heating from 90 K to 420 K with constant cooling and heating rate (4 K/min.) at cryostat pressure of 10^{-3} Torr

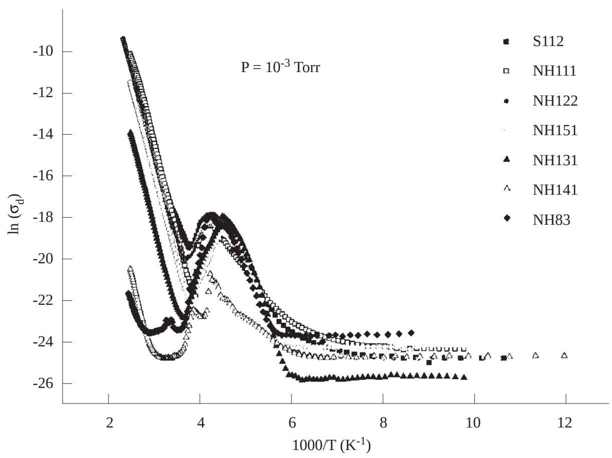

Figure 2. Dark conductivities measured, for all samples. When heating the samples from 90 K to 420 K with constant heating rate (4 K/min.) at cryostat pressure of 10^{-3} Torr

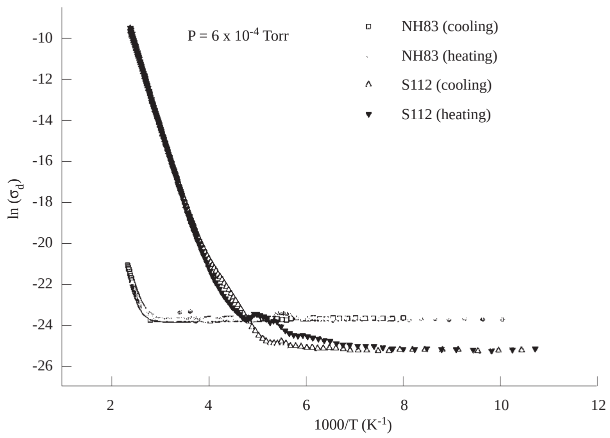

Figure 3. Dark conductivities measured, after annealing, during cooling from 420 K to 90 K and heating from 90 K to 420 K with constant cooling and heating rate (4 K/min.) at cryostat pressure of 6x10^{-4} Torr

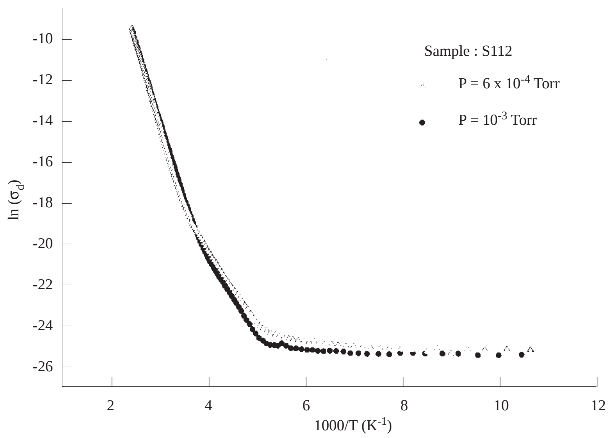

Figure 4. Dark conductivities measured, for both two cryostat pressure. When cooling the sample (S112) from 420 K to 90 K with constant cooling rate (4 K/min.)

Table 1. Dark conductivity values obtained at 235 K and 400 K for cryostat pressure of 10^{-3} Torr during cooling and heating the samples.

Sample	r	$\sigma_d(\Omega cm)^{-1}$ T=400K		$\sigma_d(\Omega cm)^{-1}$ T=235K	
		heating	cooling	heating	cooling
S112	0.00	3.2x10^{-5}	3.2x10^{-5}	1.7x10^{-8}	6.5x10^{-10}
NH111	0.05	3.7x10^{-5}	3.7x10^{-5}	9.2x10^{-9}	6.7x10^{-11}
NH122	0.10	2.3x10^{-5}	2.3x10^{-5}	1.0x10^{-8}	6.2x10^{-11}
NH151	0.15	7.7x10^{-6}	7.7x10^{-6}	2.7x10^{-9}	2.4x10^{-11}
NH131	0.25	8.4x10^{-7}	8.4x10^{-7}	4.2x10^{-9}	6.2x10^{-12}
NH141	0.50	9.9x10^{-10}	9.9x10^{-10}	7.2x10^{-10}	1.5x10^{-11}
NH83	0.90	3.0x10^{-10}	3.0x10^{-10}	1.5x10^{-8}	5.3x10^{-11}

At first sight these dark conductivity curves remind us of thermally stimulated conductivity (TSC). However, the peaks, which we have observed in this study, are not consistent with the peaks generally observed in TSC spectra of $a-Si{:}H$; one close to the illumination temperature and the other is around 300 K [1]. It is clear that this behaviour is due to the surface states under poor vacuum conditions. Similar results were reported by M. Yamaguchi [2] and Misra et. al. [3] for TSC experiments under poor vacuum conditions.

Due to its structure $a-Si{:}H$ is open to surface adsorbates. But what is interesting is that these peaks appear at the same temperature for both samples ($a-Si{:}H$, $a-SiN_x{:}H$) and therefore we conclude that alloying of samples with nitrogen does not change the energetic position of the surface states.

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