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Conductance fluctuations in undoped intrinsic hydrogenated amorphous silicon films prepared using several deposition techniques

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Abstract

Coplanar conductance fluctuations in a range of device quality undoped hydrogenated amorphous silicon (a-Si:H) films prepared using different deposition systems were measured in the temperature range of 440–505 K for frequencies from 2 Hz to 3 kHz. The $1/f^\alpha$ type noise spectra had two different power law dependencies, one at lower frequencies with slope α_1 close to unity and a second region at higher frequencies with slope α_2 around 0.60. The noise power density decreases with increasing temperature in the high frequency region, but only increases much less with temperature at low frequencies. The results indicate that the noise in undoped intrinsic a-Si:H films is due to two independent noise mechanisms operating simultaneously. © 2000 Elsevier Science B.V. All rights reserved.

1. Introduction

Hydrogenated amorphous silicon (a-Si:H) films and devices have been studied due to their importance in technological applications and the interesting fundamental physics controlling their optical and electrical properties. Since the last decade, there has been an increasing interest in $1/f^\alpha$ noise in these materials. Many of the published results have been for a-Si:H doped n-type in a coplanar geometry [1–7]. Some of these studies on n-type a-Si:H films reported unexpected properties of the excess noise such as non-quadratic dependence on dc bias current and non-Gaussian

statistics [3–5,7]. However, other studies did not find these unusual properties [6,10,11]. There have been only limited studies of noise in undoped films in a coplanar geometry [7,12–14]. One of these studies was on the noise of undoped but slightly n-type a-Si:H. Even though the expected quadratic dependence on the bias current was reported, the noise statistics were found to be non-Gaussian [12] similar to that found in some n-type a-Si:H films [3–5]. Sandwich structures have also been used to study the noise in undoped a-Si:H at and above room temperature [8–10]. A recent publication reported the expected properties of $1/f^\alpha$ noise and Gaussian noise statistics but the exponent α was frequency dependent [10]. We have also reported a noise study on intrinsic a-Si:H films using coplanar geometry [13,14]. The noise power density, S_n , had a quadratic dependence on bias current and Gaussian noise statistics. However, we found that

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the noise spectrum cannot be fit to a single $1/f^z$ power law but rather two regions each of which is fit to a power law with differing z s. These studies imply that the noise in different a-Si:H materials or different device geometries could be due to different noise mechanisms. In this paper, we have extended our earlier investigations to a larger range of undoped intrinsic a-Si:H films deposited by various deposition techniques to determine the effects of differences in the material properties on the noise spectrum and its temperature dependence.

2. Experimental

Undoped a-Si:H thin films were deposited by a variety of techniques – DC glow discharge (GD) [16], reactive magnetron sputtering [17] and radio frequency plasma enhanced chemical vapor deposition (rf PECVD), using optimized deposition conditions. For two samples the silane was diluted with hydrogen: DC GD diluted used $[H_2]:[SiH_4]$ at 3:1 and PECVD diluted at 10:1. All films have a thickness ranging from 1 to 2 μm . Coplanar Al electrodes for sputtered samples and NiCr electrodes for DC GD and PECVD samples were evaporated onto the glass substrates before the deposition. The dark conductivity activation energies of the samples varied from 0.86 to 1.05 eV. The bandgap, E_{04} (the photon energy at which the absorption coefficient equals 10^4 cm^{-1}), ranged from 1.86 ± 0.05 to 2.10 ± 0.05 eV. All the measurements used a two-probe technique and the samples current was a linearly dependent on voltage up to the largest voltages used for noise measurements. The conductance as a function of voltage ($G(V)$) relation is shown for one of the samples in the inset of Fig. 2; the standard deviation of the zero-slope fit to the $G(V)$ is less than 0.4%. Noise and conductivity measurements were carried out under one Torr of flowing helium to reduce the effects of surface contaminants. Prior to noise measurements, the samples were annealed up to 2 h at the highest measurement temperature, which was less than the deposition temperature for each sample to reduce non-reversible structural changes. The system and procedures used to ob-

tain noise spectra were described previously [6]. At each temperature, noise spectra were measured for different dc bias currents from 0.5 to 20 μA . The current density was maintained $<0.3 \text{ A/cm}^2$ to avoid sample heating. The background noise, which consists of Johnson and instrumental noise, was measured separately at every temperature and subtracted leaving only the noise due to conductance fluctuations.

3. Experimental results

For each sample, noise spectra were measured between 440 and 505 K using several bias currents at each temperature. We found that S_n had a quadratic dependence on bias current ($S_n \propto I^b$, where $b = 2.0 \pm 0.04$) and follows a $1/f^z$ noise spectrum. Examples of the noise power density spectra for different intrinsic a-Si:H films are shown in Fig. 1. The noise spectra for all the samples were fitted with two different power laws

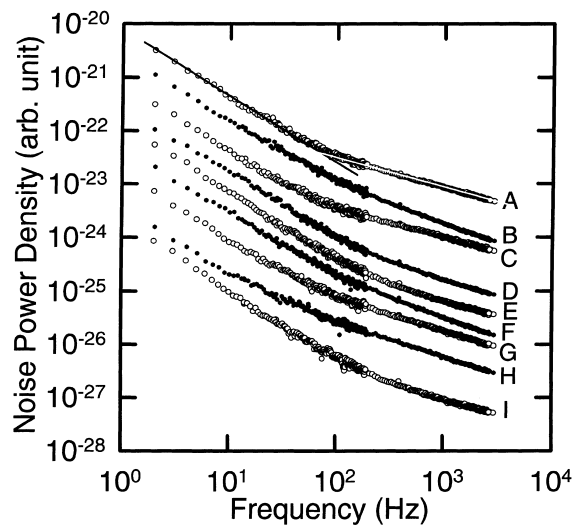


Fig. 1. The noise power density spectra of undoped intrinsic a-Si:H films deposited using different systems measured at intermediate temperatures. The spectra have been shifted vertically for clarity: (A) DC GD S260C at 471 K, (B) PECVD Diluted at 468 K, (C) DC GD Diluted at 474 K, (D) Sputtered 1586T at 473 K, (E) DC GD MBA1 at 483 K, (F) Sputtered 1936T at 479 K, (G) Sputtered 1933M at 478 K, (H) DC GD S300C at 472 K and (I) DC GD S215C at 482 K.

similar to the spectra reported earlier for DC GD intrinsic a-Si:H [14]. At lower frequencies, called region 1, the noise spectrum is represented by $1/f^{\alpha_1}$ power law, where α_1 is sample dependent and changes between 1.13 ± 0.05 and 1.27 ± 0.05 . At higher frequencies, region 2, the noise spectrum was fit to a $1/f^{\alpha_2}$ power law, where the slope α_2 was around 0.6 ± 0.03 . As seen from Fig. 1, this unusual shape of noise spectrum is observed for all the samples no matter what deposition system and conditions were used to make the film. To be certain that the unexpected shape of the noise spectrum is not an artifact caused by temperature fluctuations due to turbulence in the helium atmosphere, a copper cover was placed over the heating stage. In addition, several samples were measured in a hard vacuum less than 10^{-5} Torr. No change was observed in the noise spectra in either case. Furthermore, the noise spectrum of n-type and p-type doped a-Si:H films measured in the same vacuum chamber at similar temperatures did not have this kinked shape [18] which is found only for intrinsic films.

The effect of temperature on the magnitude and the shape of the noise spectrum is shown in Fig. 2

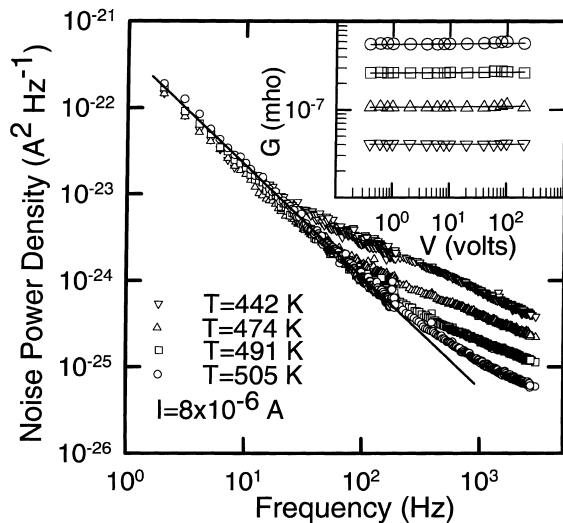


Fig. 2. The noise power density spectra of sample DC GD diluted at temperatures of 505, 491, 474 and 442 K for a bias current of $8 \mu\text{A}$. Inset: conductance versus voltage for the same temperatures. Lines are obtained from the linear regression fits to data.

for the DC GD diluted sample. Similar to previously reported results [14], the noise spectrum is fit by region 1 at 505 K. It can be fit to a single power law with $\alpha_1 = 1.29$ for all but the highest frequencies. As temperature decreases, region 2 appears with a slope of $\alpha_2 = 0.57$. It extends to lower frequencies and dominates over most of the spectrum as the temperature is further reduced. The exponent α_1 decreases to 1.19; however, the exponent α_2 remains almost unchanged. The magnitude of the noise increases in region 2, but decreases slightly at lower frequencies. Using the data in Fig. 2, the log-log plot of S_n versus temperature can be fit to a straight line ($S_n \propto T^\beta$) (data not shown) for frequencies of 5 and 1000 Hz, which encompass the changes in the noise power density in region 1 and region 2, respectively. We found that $\beta = 1.9$ for 5 Hz and $\beta = -14$ for 1000 Hz. Similar results were obtained for all the samples shown in Fig. 1. Furthermore, the statistics of the noise were also studied by measuring the correlations in fluctuations of noise power density at a set of discrete frequencies [11] for the films shown in Fig. 1. We found that the histogram of cross-correlation coefficients is centered around zero to ± 0.01 with a shape consistent with that expected for an uncorrelated noise signal [11].

4. Discussion

The $1/f^\alpha$ noise results we report here on different intrinsic a-Si:H films (where $E_\sigma = 0.86$ to 1.05 eV) are consistent with our previous study [14]. These results indicate that the same types of noise mechanisms are operating in all intrinsic samples. However, our data are not in agreement with some previously reported data on undoped a-Si:H [7,10,12]. Khera and Kakalios [7] carried out $1/f$ noise measurements of undoped a-Si:H films deposited by PECVD and hot-wire CVD systems [12] in a coplanar sample geometry at higher temperatures. In that study, the undoped a-Si:H samples were not intrinsic but slightly n-type; E_σ varied from 0.4 to 0.80 eV. The noise power density varied quadratically with bias current, but the statistics were non-Gaussian. In comparison, our undoped PECVD sample prepared with hydrogen

dilution is intrinsic with $E_\sigma = 1.02$ eV. It gives the same type of noise power spectra and temperature dependence as the other intrinsic films as well as Gaussian statistics. However, at larger bias currents, non-Gaussian switching noise was detected. The differences in the noise between undoped intrinsic and undoped non-intrinsic (slightly n-type) a-Si:H films could be an important indication for determining the noise sources in undoped a-Si:H. It was shown previously that undoped, intrinsic a-Si:H films (with $E_\sigma \geq 0.90$ eV) studied using the sub-bandgap absorption and steady-state photo-conductivity measurements also differ from undoped, non-intrinsic a-Si:H films (with E_σ from 0.6 to 0.8 eV) in that the latter contain more charged defect states in the bandgap [19,20].

Recently, a noise study was carried out on undoped intrinsic a-Si:H films from room temperature to 420 K [10]. In that work, sandwich structures (Cr-n⁺-i-n⁺-Cr) were used for the noise measurements using currents in the linear portion of the $I(V)$. The noise statistics were found to be Gaussian and the $1/f^\alpha$ noise power varied quadratically with bias current as expected. However, the exponent α was not a constant but frequency dependent. The analysis using the Dutta–Dimon–Horn (DDH) model [15] showed that the resistance fluctuations are produced by thermally activated processes, which can be described by a single distribution of activation energies. Further, the exponent $\alpha(f, T)$, now locally defined, obtained from the DDH model and that directly calculated from the measured spectra agreed. These results imply that the temperature and frequency dependence of the noise is consistent with a single distribution of thermally activated processes which peaks around 0.85 eV. They proposed that a generation-recombination model with continuous distribution of trap levels could be the dominant noise mechanism in undoped a-Si:H.

In order to determine if the DDH model could be applied to our data from intrinsic a-Si:H films, we replotted the data shown in Fig. 2 as the noise power density versus temperature for three frequencies of 5, 50 and 1000 Hz (plot not shown), where 5 and 1000 Hz were chosen to represent regions 1 and 2, respectively and 50 Hz the transition region between the two. For each frequency

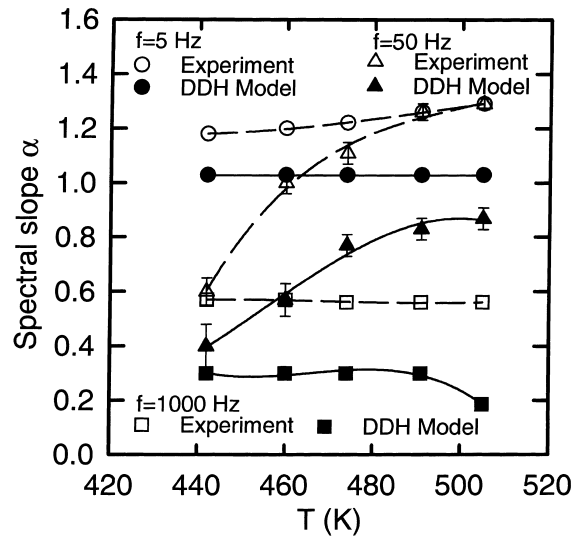


Fig. 3. Spectral slope α versus temperature for sample DC GD diluted for three different frequencies. Open symbols were obtained from the slope of measured noise spectra and filled symbols were calculated from the noise data using the equation derived in the Dutta–Dimon–Horn model. Solid and dashed lines are guides to eye.

curve, the exponents $\alpha(f, T)$ were calculated using the DDH model (Eq. 4 in Ref. [15]). An attempt rate, f_0 , of 10^{12} s⁻¹ was assumed for the calculation of $\alpha(f, T)$. $\alpha(f, T)$'s were also obtained at the same frequencies and temperatures from the slope of the noise spectrum. These results are illustrated in Fig. 3 for the DC GD diluted sample. It is seen that no agreement is found between the $\alpha(f, T)$ s obtained from the DDH model and those calculated from the experimental spectra. The DDH model always underestimates the exponent, $\alpha(f, T)$. These underestimation would indicate that either some of the assumptions in the DDH model are not satisfied or the noise is not due to independent activated processes in our coplanar samples unlike the sandwich devices.

5. Conclusions

The noise study carried out on undoped intrinsic a-Si:H films deposited in different systems with a coplanar geometry gives consistent noise power spectra. It shows two different regions,

region 1 at lower frequencies with the exponent α_1 close to unity and region 2 at higher frequencies with α_2 around 0.60. It can be inferred that there are two independent noise sources acting simultaneously in intrinsic a-Si:H. At present their origin is not known. To understand these possible noise sources and their statistics, an extensive noise study on undoped non-intrinsic (slightly n-type) a-Si:H films deposited by different systems is underway and will be reported in the near future.

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