Conductance fluctuations in a-Si : H: effects of alloying and device structure

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We present measurements of conductance noise in undoped a-Si : H and a-SiGe : H thin films in both a transverse and coplanar electrode geometry. For a-Si : H with coplanar electrodes, the noise spectrum is not a pure $f^{-\alpha}$ power law but consists of two linear regions with different slope parameters α. The spectral shape and its temperature dependence are similar for all samples, regardless of the growth technique. Adding Ge results in qualitatively similar spectra; however, α at high frequencies and the temperature dependence are altered. For both a-Si : H and a-SiGe : H with transverse electrodes, the noise spectra are pure $f^{-\alpha}$ power laws, and α decreases with the Ge content.

1. Introduction

Hydrogenated amorphous silicon (a-Si : H) is an interesting material for studying 1/*f* conductance noise. Much is known about its electronic structure, especially the distribution of localized gap states, and several noise studies have appeared in the literature [1–9]. Despite consistency among the reported work from each individual laboratory, there are noted discrepancies in the data and explanations between laboratories. Some of these discrepancies might be due to differences in device geometry or the type and quality of the a-Si : H samples. Still, it is troubling that data from samples of nominally the same doping and sample geometry produce different reported noise characteristics [3–5]. In particular, some studies of n-type a-Si : H report unexpected phenomena for 1/*f* noise such as non-Gaussian statistics and a nonlinear dependence on the bias current [3, 4, 6].

Due to the high resistance of undoped a-Si : H, most noise measurements have involved either n-type [3–6] or p-type [10] material, and then mostly with the electrodes in a coplanar geometry, i.e., the current path is parallel to the free surface of the thin film. Undoped films have been studied using a transverse electrode geometry, i.e., the current path is perpendicular to the free surface [1, 2, 7–9], or a coplanar geometry [6, 11–13] but only at temperatures much above room temperature. There are also discrepancies among the published results on undoped a-Si : H. No noise studies of amorphous silicon–germanium alloys (a-SiGe : H), either in a coplanar or a transverse geometry, have appeared in the literature, except for some preliminary results we recently published [14]. In this paper, we present further data on 1/*f* noise in a-Si : H and a-SiGe : H, and investigate the effect of alloying and electrode geometry.

2. Experimental details

Samples of undoped a-Si : H were prepared using several standard deposition techniques – d.c. glow discharge (GD), r.f. plasma-enhanced chemical vapor deposition (RF-PECVD) with and without hydrogen dilution, r.f. magnetron sputtering, and hot-wire chemical vapor deposition (HW-CVD) – using conditions optimized (to produce low defect concentrations), device-quality material. Undoped a-SiGe : H films on glass substrates with coplanar electrodes and n-i-n transverse a-Si : H and a-SiGe : H samples on stainless steel (SS) substrates were deposited in a RF-PECVD reactor at United Solar Systems Corp. Their Ge contents were measured using EDX/SEM. The thicknesses of the samples ranged from 1 to 2 μm. For the n-i-n transverse samples, Cr dots, 1.6 mm in diameter, were evaporated on the top n^+ layer. Each device was isolated by scribing around the dot down to the SS substrate, to eliminate any current flow to other dots. Some of the HW-CVD coplanar samples had a 12-nm thick, heavily doped n^+-layer between the metal contact and the sample, to improve ohmicity. All measurements used a two-probe geometry.

The system and procedures used to obtain noise spectra have been described previously [5]. At each

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temperature, the ohmicity of the contacts was checked, and in all cases the bias current was linearly dependent on voltage up to the largest bias current used for the noise measurements. Noise spectra were obtained for several d.c. bias currents, to check the dependence of the noise magnitude on the bias current. The background noise, which consists of Johnson noise and instrumental noise, was measured separately at each temperature and subtracted, leaving only the noise due to conductance fluctuations.

3. Results and discussion

3.1. Noise in coplanar undoped a-Si : H

Fig. 1 shows examples of noise spectra for an undoped a-Si : H film at 516 K, prepared by HW-CVD. Although the noise magnitude depends quadratically on the d.c. bias current, as it should, the data do not fit a simple $f^{-\alpha}$ power law. Instead, they display two regions each of which fits to $f^{-\alpha}$ but with different α values. We have reported this kind of kinked spectrum previously [12, 13]. Region 1, at lower frequencies, has an α_1 substantially higher than α_2 in Region 2, at higher frequencies. We find that α_1 is sample dependent, varying from 1.10 ± 0.02 to 1.30 ± 0.02, and decreases slightly with temperature. In contrast, α_2 is 0.60 ± 0.05, independent of sample and temperature. As the temperature decreases, the magnitude of the noise in Region 2 increases, whereas the magnitude in Region 1 is almost unchanged. Thus, at a sufficiently low temperature, the noise spectra over the measured frequency range becomes completely dominated by Region 2, and a single power law is observed as shown in the inset to Fig. 1. Likewise, at a sufficiently high temperature, Region 1 would dominate and a single power law (with a different slope) would be observed. Because this noise spectrum is unusual, we asked researchers at the University of Abertay Dundee to measure one of our samples, and their data at 442 K are in agreement with ours.

Similar noise spectra have been observed in other undoped a-Si : H films deposited in several deposition systems, as previously reported [13]. As shown in the inset of Fig. 1, the noise power in Region 2 decreases substantially with increasing temperature. Fitting the noise power in Region 2 to a power law $S_n \propto T^d$ results in $d \approx -2$. Other samples produced similar d values.

In addition, the noise signal was tested for non-Gaussian components by measuring the correlation between the noise power at separated frequencies and by measuring the second spectrum. Both tests resulted in Gaussian noise statistics.

3.2. Noise in coplanar undoped a-SiGe : H

The noise spectra of undoped a-SiGe : H are qualitatively similar to those of unalloyed material. Examples for an alloy with 15 at % Ge at 492 K are shown in Fig. 2, for four d.c. bias currents. At this temperature, the noise spectra fit to a power law with $\alpha_1 = 1.23$, similar to that observed for a-Si : H samples. As the temperature is reduced, Region 2 appears (inset of Fig. 2). However, $\alpha_2 = 0.44$, which is lower than the value found for a-Si : H. As observed for a-Si : H, the noise in Region 2 continues to increase at lower temperatures, and eventually dominates the noise spectrum.

a-SiGe : H films with higher Ge content exhibit similar behavior. α_1 varies from sample to sample, ranging from 1.20 ± 0.02 to 1.48 ± 0.02 and changes slightly with

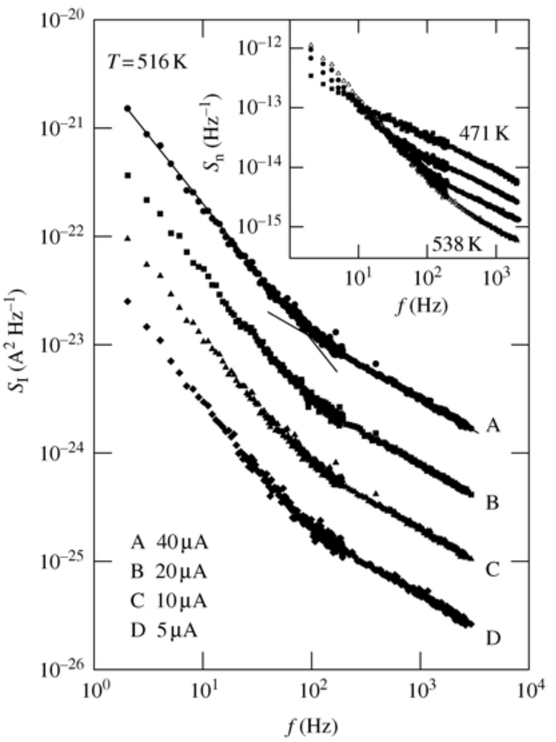

Figure 1 Noise spectra of a HW-CVD a-Si : H film at 516 K, for the four d.c. bias currents shown. Inset: normalized noise spectra at 471, 495, 516, and 538 K.

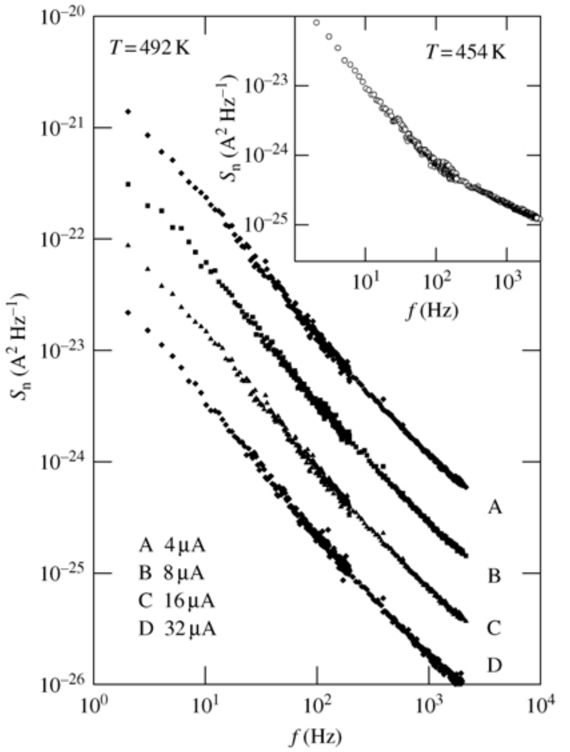

Figure 2 Noise spectra of a SiGe:H alloy with 15 at % Ge at 492 K, for the four d.c. bias currents shown. Inset: noise spectrum at 454 K for an 8-μA bias current.

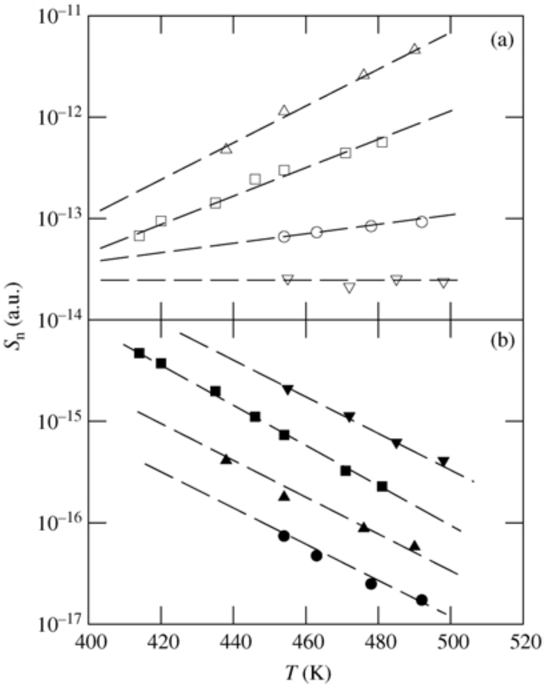

Figure 3 Temperature dependence of the noise magnitude at (a) 5 Hz and (b) 3 kHz for a-Si : H (inverted triangles) and a-SiGe : H with 15 (circles), 25 (squares), and 40 (triangles) at % Ge. The spectra are shifted vertically for clarity.

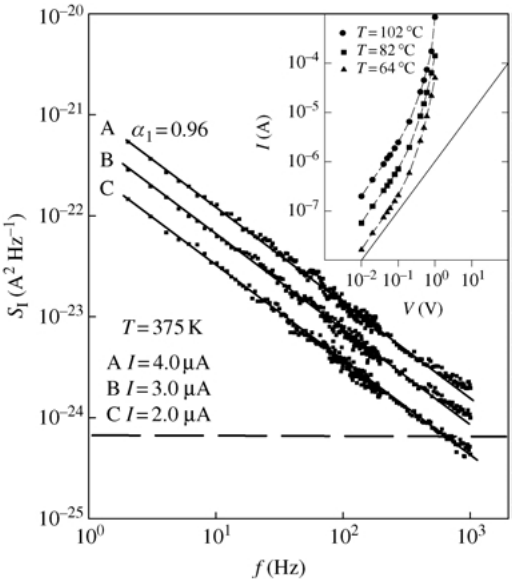

Figure 4 Noise spectra of a-Si : H with transverse electrodes at 375 K for three d.c. bias currents. The inset shows the *I–V* characteristics of the contacts. The broken line indicates the background noise.

temperature. However, for Region 2, α_2 varies systematically with Ge content, decreasing from 0.60 for the pure a-Si : H samples to 0.44 for 15 at % Ge, 0.27 for 25 at % Ge, and 0.15 for 40 at % Ge.

Furthermore, adding Ge has an additional effect on the temperature dependence of the noise magnitude. In Region 1, the noise power density at 5 Hz is almost independent of temperature for a-Si : H, but is increasingly temperature dependent as Ge is added, as shown in Fig. 3(a). Fitting to $S_n \propto T^d$ yields d values of 4, 12, and 18 for 15, 25, and 40 at % Ge respectively. However, in Region 2, the noise power density depends on temperature in a similar manner to that observed for unalloyed a-Si : H (Fig. 3(b)). The Ge content has no effect on the temperature dependence, with d near -20 for all samples. As with the a-Si : H samples, the noise power of the a-SiGe : H alloys varies quadratically with bias current. Likewise, the signal was tested for non-Gaussian components and in all cases was found to be Gaussian.

3.3. Noise in undoped n-i-n a-Si : H

Due to the high resistance of undoped coplanar samples at room temperature, n-i-n transverse structures were first used to study the conductance noise in a-Si : H [1, 7–9]. However, the noise spectra and their characteristics were found to depend on the device geometries. To investigate these effects, we extended our investigation to n-i-n structures. We measured the activation energy of the dark conductivity of several dots on the same substrate, and identified good devices before taking any noise measurements. The activation energy of the transverse dark conductivity for undoped a-Si : H films was found to be 0.76 eV, which is slightly lower than that of sister coplanar a-Si : H samples (0.82 eV). The difference is likely to be due to band bending at the surface. The contacts were ohmic up to 0.2 V, as shown in the inset of Fig. 4.

Noise spectra for an a-Si : H n-i-n transverse structure at 375 K are shown in Fig. 4, for three d.c. bias currents. The noise power spectra fit well to a simple $f^{-\alpha}$ power law with $\alpha = 0.96$ and show the expected quadratic dependence on d.c. bias current. We find that α does not depend on frequency for a-Si : H sandwich structures, in disagreement with the results reported in [9]. This behavior is also different from that observed in coplanar samples, in that there is no distinct break in the spectra. Noise spectra measured for other dots on the same substrate produced the same results. Due to limitations of the sample and the system, it was not possible to observe the temperature dependence of the noise for this sample.

3.4. Noise in n-i-n a-SiGe : H

In order to investigate the effect of Ge content in transverse structures, noise measurements were conducted for transverse, n-i-n a-SiGe : H alloys. Similar attention was paid to characterizing each device on the substrate, before noise measurements. The dark conductivity activation energy of several dots was 0.70 eV, which is close to that found for coplanar samples. The contacts were ohmic up to 2 V. The noise spectra of each sample were measured for several d.c. bias currents, at each temperature. Fig. 5 shows the effect of Ge on the normalized noise power. The noise spectra for all transverse samples fit to $f^{-\alpha}$, again unlike that seen in coplanar samples. α decreases as Ge is added, going from 0.96 for a-Si : H to 0.70 for 15 at % Ge, 0.63 for 25 at % Ge, and 0.56 for 40 at % Ge. The noise magnitude in the alloy decreases with temperature for all samples, as shown in the inset to Fig. 5. Fitting to $S_n \propto T^d$ for the a-SiGe : H alloys yields similar d values of -12 ± 0.6. Thus, the Ge content in the alloy does not affect the temperature dependence of noise magnitude, but only alters the slope, α. In addition, the noise power also obeys

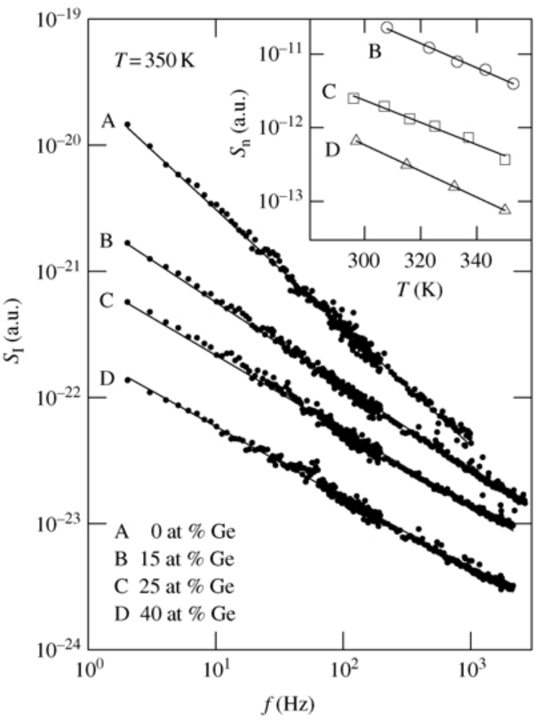

Figure 5 Noise spectra of a-Si : H and a-SiGe : H with various concentrations of Ge as shown at 350 K. All samples have transverse electrodes. Inset: temperature dependence of the noise power for the three alloyed samples at 5 Hz.

a quadratic dependence on the d.c. bias current, and shows Gaussian noise statistics as expected.

4. Conclusions

There is a qualitative difference in the behavior of the noise between the transverse and coplanar specimen geometries. Two possible explanations present themselves. First, the current path in a coplanar sample is always near the surface, and an interaction with surface states might produce one of the branches of the noise spectra observed in these samples. In contrast, the transverse current path passes through the bulk of the sample, and thus the noise spectrum is due only to mechanisms operating there. Alternatively, recent work suggests that current flow in a-Si : H is not uniform, but is confined to filaments. If that is the case, then coplanar samples would have a few rather long filaments carrying most of the current, but transverse samples would have many short filaments. How this would affect the noise is difficult to say, except that for the transverse samples an average over the many filaments might tend to produce a simple power-law behavior. However, because the coplanar and transverse samples were measured over different, non-overlapping temperature ranges, we can not rule out the possibility that the noise spectrum for the transverse geometry is simply the low temperature extrapolation of the spectrum for the coplanar samples. A detailed discussion of the existing models of noise in a-Si : H is given in a recent review paper [15]. Clearly, more work is needed to understand the noise of a-Si : H and its alloys.

Acknowledgments

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