Conductance fluctuations in VHF-PECVD grown hydrogenated microcrystalline silicon thin films

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Coplanar conductance fluctuations or excess noise of undoped hydrogenated microcrystalline silicon (μc-Si : H) thin films grown by VHF-PECVD from silane–hydrogen mixtures with silane concentrations from 2% to 6% have been studied between room temperature and 470 K. We report that undoped μc-Si : H thin films show similar noise-power spectra to those of undoped a-Si : H films in a coplanar sample geometry. At lower temperatures, the noise with the slope $\alpha = 0.60 \pm 0.07$ and at higher temperatures, the noise with the slope α close to unity dominate the spectrum. The noise magnitude decreases with decreasing silane concentration and becomes strongly temperature dependent with increased crystallinity.

1. Introduction

Hydrogenated microcrystalline silicon (μc-Si : H) has potential applications in large-area electronics such as solar cells, flat-panel displays, and optical sensors. Due to its heterogeneous micro-structure, there exists a mixed phase of disordered and crystalline regions causing a wide range of electronic transport properties. Mostly, the same characterization tools established for a-Si : H films have been applied to study transport properties of μc-Si : H. Among these tools, 1/*f*-type noise has recently been another characterization method to study the fundamental properties of a-Si : H-based semiconductors [1]. However, there has not been any noise study reported for μc-Si : H films yet. In this paper, we present the first observations of excess noise characteristics of coplanar μc-Si : H films prepared with different silane concentrations SC in the silane–hydrogen process-gas mixture.

2. Experimental methods

μc-Si : H films were prepared in a multi-chamber VHF-PECVD deposition system with SC = 2 and 6%, with thicknesses of 2 μm on glass substrates [2]. Then, a 20-nm heavily doped n^+-layer was deposited on the film using a mask, before the coplanar silver contacts were evaporated.

The system and procedures used to obtain the noise spectra have been described previously [3]. At each temperature, the ohmic character of 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. The background noise, which consists of Johnson noise and instrumental noise, was measured separately at each temperature and subtracted from each spectrum, leaving only the noise due to conductance fluctuations.

3. Results

Noise-power spectra at 382 K for the sample prepared with SC = 6% are shown in Fig. 1 for four d.c. bias currents. The noise magnitude shows a quadratic dependence on d.c. bias current, meaning that the d.c. bias current does not generate the noise but is used only to probe it. The spectra obey a pure $1/f^{\alpha}$ power law, where the exponent α is 0.68, i.e. lower than unity. As temperature is increased above 405 K, a second region at lower frequencies with higher slope exists in the noise spectra and extends to higher frequencies with increasing temperature, as shown in the inset. The lower-frequency region can also be fit to a power law with a slope $\alpha = 1.23$. The noise magnitude at higher frequencies drastically decreases with temperature and the slope of the higher-frequency branch, $\alpha = 0.68$, is almost temperature independent. The noise spectra for the SC = 6% film are similar to those observed for undoped a-Si : H films [4, 5]. With Raman spectroscopy it was confirmed that at SC = 6% the material is a mixture of amorphous and crystalline regions, while at SC = 2% the material is almost fully crystalline [2].

The sample prepared with a 2% silane concentration contains a higher crystalline volume fraction and less amorphous phase, as reported previously [2]. With the higher crystallinity at SC = 2%, the films are more

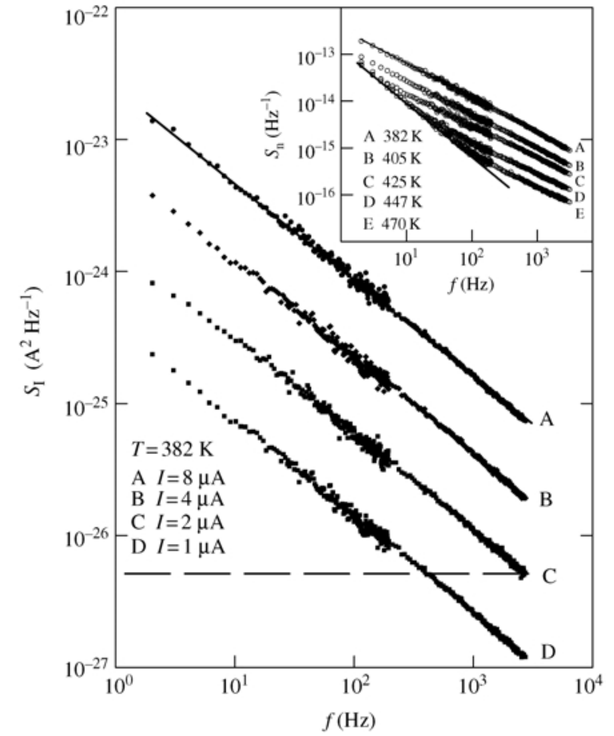

Figure 1 Noise-power-density spectra of μc-Si : H prepared with 6% silane, for four bias currents. The dashed line indicates Johnson noise. In the inset, normalized noise-power spectra are shown for different temperatures.

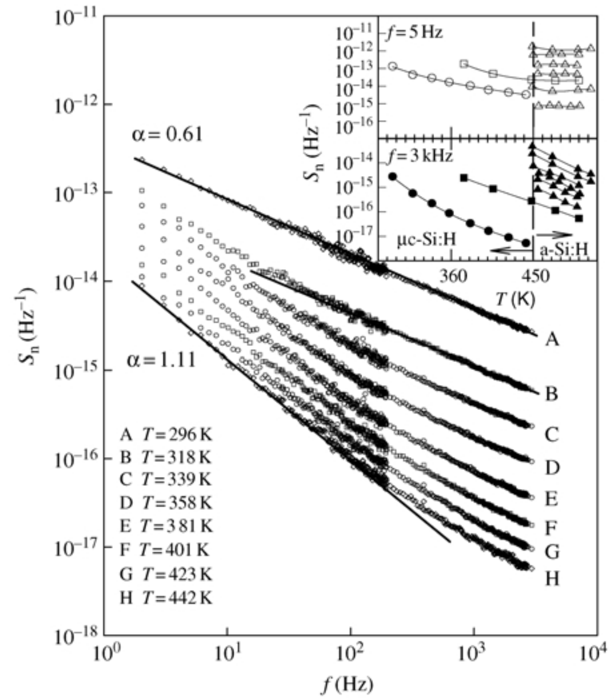

Figure 2 Normalized noise spectra for c-Si : H film prepared with 2% silane for different temperatures. In the inset, the temperature dependence of the normalized noise at 5 Hz (open symbols) and 3 kHz (filled symbols) are shown for SC = 2% (circles), SC = 6% (squares), and a-Si : H films (triangles). For a-Si : H films, the magnitude of the normalized noise has been shifted vertically for clarity.

conductive and allow us to measure conductance fluctuations at lower temperatures. Normalized noise spectra for the SC = 2% sample are shown in Fig. 2. At room temperature, the noise power follows a pure $1/f^{\alpha}$ law, with $\alpha = 0.61$. As the temperature is increased, the second noise mechanism with its characteristic slope of unity starts dominating the spectrum at lower frequencies. The slope is 1.0 at 318 K and slightly increases to 1.11 at 442 K. However, the 0.61 slope of the high-frequency branch remains independent of temperature, as observed in the 6% μc-Si : H film.

In addition, the normalized noise magnitude decreases as SC decreases from 6% to 2%, and shows a stronger temperature dependence both in the lower- and higher-frequency branches, as given in the inset of Fig. 2 (the volumes are equal for both samples). At 5 Hz, the noise for the SC = 6% film is independent of temperature down to 450 K, as observed in undoped a-Si : H. Below 450 K, for both μc-Si : H films, the noise increases substantially as T decreases. At 3 kHz, the temperature dependence of the noise in the SC = 6% film above 450 K is exactly similar to that for a-Si : H. The noise magnitude in this temperature range can be fitted to $S_n \propto T^{\beta}$, where the β values are around -20. For the SC = 2% film at 3 kHz, the noise shows a stronger temperature dependence than the power law defined for a-Si : H. Furthermore, for both samples at every temperature, the noise signal was tested for non-Gaussian components by measuring the correlation between the noise power at separate frequencies and the second spectrum. Both tests indicated that the noise statistics is Gaussian.

4. Conclusions

We have reported the first observations of the excess-noise characteristics of μc-Si : H films in a coplanar sample geometry. These results indicate that there are two different noise sources operating in μc-Si : H films. One dominates the spectrum at lower temperatures, with a lower slope, $\alpha = 0.60 \pm 0.08$, and shows a strong temperature dependence. The second dominates the spectrum at higher temperatures, with a higher slope of α, close to unity. Similar noise spectra have also been observed in a-Si : H films above 450 K [4, 5]. We conclude that similar noise mechanisms are operating in both a-Si : H and μc-Si : H films. However, the natures of these sources are not yet known.

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