Thin Solid Films 518 (2010) 3310–3312

Contents lists available at ScienceDirect

Thin Solid Films

journal homepage: www.elsevier.com/locate/tsf

Noise in micro-bolometers with silicon-germanium thermo-sensing layer

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ARTICLE INFO

Article history:
Received 11 May 2009
Received in revised form 15 September 2009
Accepted 29 September 2009
Available online 8 October 2009

Keywords:
Silicon-germanium films
Plasma deposition
Electrical properties and measurements
Electronic devices

ABSTRACT

Low frequency noise in a-Si_xGe_y:H thermo-sensing films, on glass and in micro-bolometers of planar and sandwich structures based on the same material has been studied at different temperatures. The noise spectra had the form of the 1/*f*-like noise with the frequency exponent within the range of 0.8 to 1.6 depending on the sample and temperature. In the temperature range from $T=340$ to 400 K the amplitude of the noise and current (at constant voltage) increased. These dependences can be described as a thermal activated process with energies of $E_a^{S/I}=0.63$ eV and $E_a^{film}=0.34$ eV for relative spectral noise density of the current fluctuations and DC current, respectively.

1. Introduction

The development of un-cooled micro-bolometers (UC MB) based on plasma deposited materials, and compatible with standard silicon based technology, has paved the way for low cost, large scale 2D IR imaging devices. Several companies already offer commercial production of 2D IR arrays based on plasma deposited a-Si:H(B) or poly silicon-germanium layers. Among them "Raytheon" (USA) [1], "Ulis IR-LETI" (France) [2], and "XenICs" (Belgium) [3] can be mentioned. We have previously published studies on UC MB based on a-Si-Ge:H thermo-sensing films deposited by low frequency plasma enhanced chemical vapor deposition (LF PECVD) [4–6]. An important part of the performance characterization of UC MB is the measurement of the noise characteristics [4–6], which, in conjunction with the responsivity determine the detectivity. The latter is a rather a universal parameter, which incorporates signal-to-noise ratio that allows the comparison between different detectors. However, the noise has not been sufficiently studied in non-crystalline materials (see, for example, [7–9]) and for the case of UC MB, there is even less information. To date, there are only a few publications, which report experimental data on noise measurements in micro-bolometers [10].

In this paper, we present the experimental study of noise in UC MB of two configurations: planar and sandwich structures with a-Si_xGe_y:H as a thermo-sensing film. Additionally, the noise was measured in the same films deposited on glass substrates.

2. Experimental details

The detailed description of the UC MB fabrication process on silicon wafer can be found elsewhere [11]. Both planar and sandwich configurations of UC MB studied are shown in Fig. 1. A 0.5 µm-thick a-Si_xGe_y:H layer was deposited by a LF PECVD technique at a frequency $f_{LF}=110$ kHz, deposition temperature $T_d=300$ °C, power $W=350$ W and pressure $P=80$ Pa. The a-Si_xGe_y:H layer was deposited from a $SiH_4+GeH_4+H_2$ gas mixture with the following flow rates: $Q_{SiH4}=25$ sccm, $Q_{GeH4}=25$ sccm and $Q_{H2}=1000$ sccm. Measurements of the film compositions by secondary ion mass spectroscopy showed the germanium content in the bulk to be $y=0.88$. The active area in UC MB is $S_B=66\times40$ µm^2. The separation of the electrodes in the planar UC MB is $D_e=40$ µm. The structure of the sample with thermo-sensing film for noise measurements on glass substrate ("Corning-1737"), consisted of Ti electrodes in the form of stripes deposited on glass and coated by the a-Si_xGe_y:H film. The length of the electrodes was $L_e=3$ mm and the inter-electrode distance was $D_e=1.5$ mm. For the sandwich structures the inter-electrode distance was $D_e=0.5$ µm.

The characteristics of UC MB and that of the film on glass substrate were both measured in a vacuum thermostat with a ZnSe window for illumination. The measurement of the temperature dependence of conductivity in both UC MB and the film-on-glass samples, provided the room temperature conductivity $\sigma_{RT}=6\times10^{-5}$ Ohm^{-1} cm^{-1}, and an activation energy $E_a^{film}=0.34$ eV. The latter corresponds to a temperature coefficient of resistance, $\alpha=-0.04$ K^{-1}.

The experimental set-up used for the noise measurement is shown in Fig. 2. For the noise measurements, the voltage fluctuations from the load resistance were amplified by the high impedance amplifier and then analyzed by the lock-in amplifier "SR-530" in the regime of quadratic detection. A bandwidth $\Delta f=1$ Hz in the frequency range of

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0040-6090/$ – see front matter
doi:10.1016/j.tsf.2009.09.122

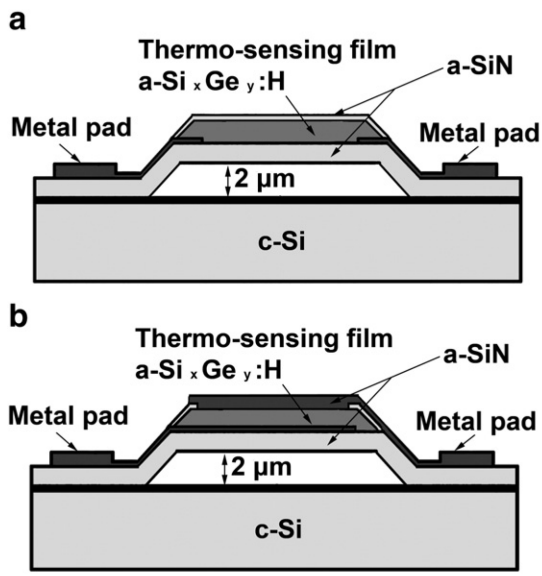

Fig. 1. Planar (a) and sandwich (b) configurations of the micro-bolometers.

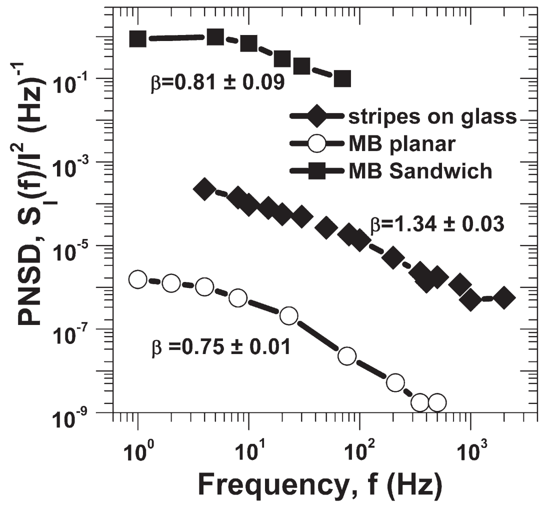

Fig. 3. Power noise spectral density scaled by current squared $S_I(f)/I^2$ for planar and sandwich micro-bolometers and a-Si_xGe_y:H ($y=0.88$) thermo-sensing film on glass substrate.

$f=1$–10^5 Hz was used. The power noise spectral density (PNSD) of the low frequency short circuit current fluctuations was calculated as $S_I(f)=\frac{S_V-S_{bv}}{R_{eq}^2}$, where S_v is the measured voltage noise, S_{bv} is the background system noise obtained by the measurements at zero bias, $R_{eq}=\frac{R_B R_L}{R_B+R_L}$, R_B is the bolometer (film) resistance and R_L is the load resistor. During the noise measurements at different temperatures the bias voltage U_B was kept constant.

3. Results and discussion

Fig. 1 shows planar (a) and sandwich (b) configurations of UC MB used in our experiments. The fabrication process, materials of the thermo-sensing films, and deposition parameters were the same for both structures. Since the direction of the current flow is different for the planar and sandwich structures (along the film or perpendicular to the film surface, respectively), the resistance of the sandwich UC MB was significantly smaller than that of the planar ones. The active area was practically the same for both structures.

For all samples at all temperatures the PNSD of the current noise S_I was proportional to the square of the current. Fig. 3 shows PNSD S_I/I^2 for different samples. In the curves of Fig. 3, it is possible to distinguish two regions: low frequency region where $S_I(f)\sim 1/f^{-\beta 1}$, with $\beta 1$ in the range of 0.75 to 0.81 and the higher frequency region, where $S_I(f)\sim 1/f^{-\beta 2}$ and $\beta 2\approx 1.34$. This behavior differs from the typical "1/f" noise, where $S_I(f)\sim 1/f^{-1}$. It is interesting to note that the planar structure of the UC MB and the thermo-sensing film on glass showed relatively small level of noise in comparison with sandwich UC MB.

The temperature dependence of $S_I(f)/I^2$ is presented in Fig. 4 for the thermo-sensing film deposited on glass. It is seen that the noise increases with temperature across the entire frequency range. More attentive analysis revealed that the "β" parameters changed with temperature as shown in Fig. 5. $\beta 2$ increases remarkably from 1.2 to 1.7, while $\beta 1$ changes weakly with temperature. In the inset of Fig. 4 a temperature dependence of noise S_I/I^2 at $f=4$ kHz is shown. Its behavior in the range of temperature from $T=340$ K to 400 K can be described as a thermal activation process with an activation energy of $E_a^{S/I}=0.63$ eV. Since dc current also increases exponentially with the temperature increase (activation energy $E_a^{film}=0.34$ eV), the spectral

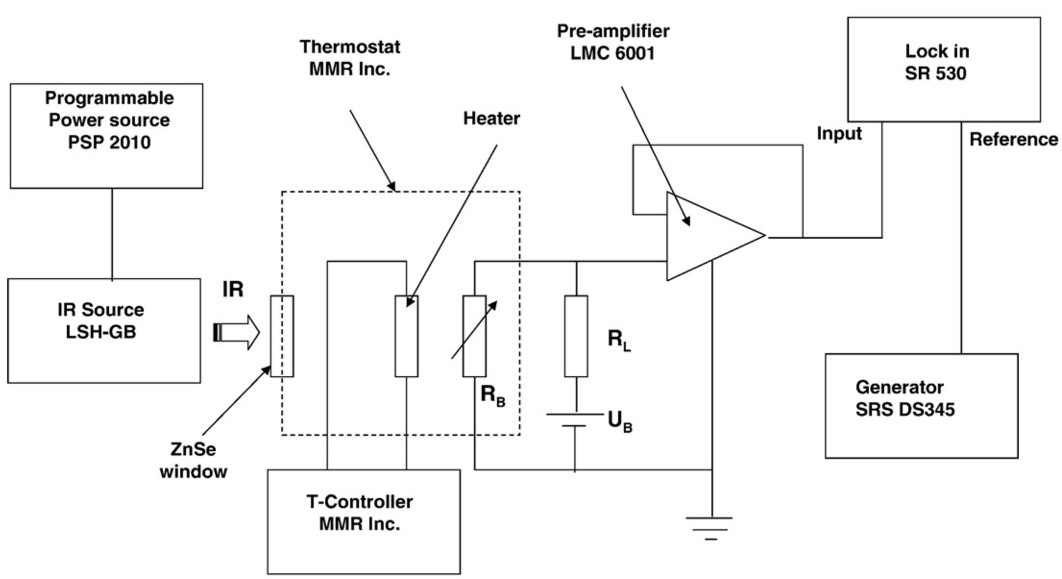

Fig. 2. Experimental set-up employed for noise measurements at various temperatures.

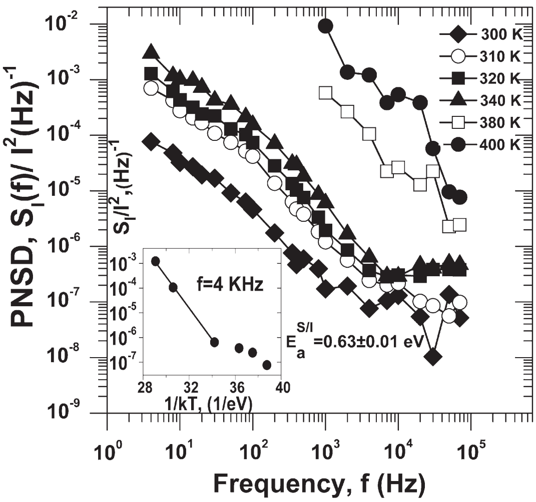

Fig. 4. Power noise spectral density scaled by current squared $S_I(f)/I^2$ of thermo-sensing layer a-Si_xGe_y:H ($y=0.88$) on glass at different temperatures. The inset shows $S_I(f=4\text{ kHz})/I^2=f(T)$.

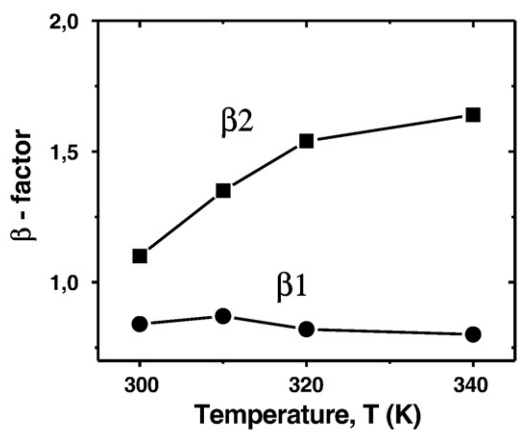

Fig. 5. β-factor as a function of temperature for a-Si_xGe_y:H ($y=0.88$) thermo-sensing film.

noise density S_I measured at constant voltage exponentially depends on temperature with the activation energy $E_a^S=E_a^{S/I}+2E_a^{\rm film}\approx 1.3$ eV.

Many models have been proposed for explaining the $1/f$ noise, but there is no generally accepted theory. The models consider bulk and interface effects, fluctuations in both mobility and carrier concentration due to various reasons e.g. trapping–detrapping processes, fluctuations related to lattice, hydrogen movement in hydrogenated semiconductors, contacts etc. Comparing the results presented here with those reported for films prepared by plasma, and, first of all, with those obtained for a-Si:H films, we observe some similarity, e.g. in the reported β-values ranging from 0.6 to 1.4 [7] and the trend of $\beta 2$ change with increasing temperature from 1.15 to 1.3 [7]. However, in [7], different activation energies were found for the noise (0.1 eV) and for the conductivity (0.3 eV), which is contrary to our observations.

4. Conclusions

We have studied the noise properties in three configurations of samples with the same semiconductor film of a-Si_xGe_y:H deposited by LF PECVD. In the frequency range from 10 to 10^3 Hz the noise spectra $S_I(f)$ had the form $S_I(f)\sim 1/f^{\beta}$ with the β value varying from $\beta\approx 1.34$ to $\beta\approx 0.8$ depending on the frequency range and temperature. The amplitude of the noise differed essentially for planar and sandwich structures. In the temperature range from $T=340$ to 400 K noise increases and this dependence can be described as a thermal activated process with energy $E_a^{S/I}=0.63$ eV for the relative spectral noise density S_I/I^2 and $E_a^S\approx 1.3$ eV for the noise S_I measured at constant voltage.

Acknowledgement

The authors from INAOE acknowledge the support of this research by CONACyT project No. 48454 and I. Cosme acknowledges the scholarship of CONACyT No. 207900.

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