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Noise Spectra of Si_x Ge_y B_z:H films for micro-bolometers

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ABSTRACT

Noise spectra in plasma deposited $Si_xGe_yB_z$:H thermo-sensing films for micro-bolometers have been studied. The samples were characterized by SIMS (composition) and conductivity (room temperature conductivity, activation energy) measurements. The noise spectra were measured in the temperature range from *T*= 300 K to *T*=400 K and in the frequency range from *f*=2 Hz to *f*=2x10^4 Hz. The noise spectra $S_I(f)$ for the samples $Si_{0.11}Ge_{0.88}$:H and $Si_{0.04}Ge_{0.71}B_{0.23}$ can be described by $S_I(f) \sim f^{-\beta}$ with $\beta = 1$ and $\beta = 0.4$, respectively. For the sample $Si_{0.05}Ge_{0.67}B_{0.26}$ two slopes were observed: in low frequency region f≤ 10^3 Hz β_1= 0.7 and at higher frequencies *f*>10^3 Hz β_2= 0.13. Increasing temperature resulted in an increase of noise magnitude and a change of β values. The latter depended on film composition. The correlation observed between noise and conductivity activation energies suggests that noise is due to bulk rather than interface processes. Noise spectrum of the thermo-sensing film $Si_{0.11}Ge_{0.88}$:H was compared with that for micro-bolometer structure with the same thermo-sensing film. The micro-bolometer structure showed higher noise value in entire frequency range that assumed additional processes inducing noise.

INTRODUCTION

Thermal detectors (bolometers) based on plasma deposited films have demonstrated many attractive advantages such as high responsivity, moderate resistance, compatibility of the fabrication process with standard silicon CMOS technology. Pioneering works with boron doped amorphous silicon in this field have been reported by "LETI" [1] and "Raytheon" [2] In our previous works we have reported on the study of fabrication and characterization of micro-bolometers with non doped silicon-germanium thermo-sensing films [3-5]. Noise measurements are of principal importance for performance characterization of the devices, because noise and responsivity determine detectivity that is a figure of merit based on signal-to-noise ratio enabling a comparison of different detectors (not only thermal ones). Another reason to study noise is related to its high sensitivity to fabrication and material parameters. So far noise in thermo-sensing materials and micro-bolometers has been poorly reported in literature. Only a few papers considered noise in plasma deposited non-crystalline materials [6 and references therein]. Noise related data for micro-bolometers can be found in refs. [7, 8].

The goal of this work is to study experimentally noise spectra in several plasma deposited thermo-sensing films used in micro-bolometers.

EXPERIMENT

The $Si_xGe_yB_z$: H films were deposited by low frequency (LF) plasma enhanced chemical vapor deposition (PE CVD). Deposition parameters were as follows: substrate temperature

T_s= 300 ^oC, power W = 450 W, the discharge frequency f=110 kHz, pressure P= 0.6 Torr, a gas mixture consisting of silane (SiH_4), germane (GeH_4) and diborane (B_2H_6) diluted with hydrogen. Composition of the films was changed by means of the variation of flows of the aforementioned gases (details see e.g. in ref. [9]). Composition of the films was determined by SIMS profiling. The films were deposited on glass ("Corning 1737") substrates for electrical and optical characterization and on Si substrates for IR and SIMS analysis. The characteristics of the thermo-sensing films studied are listed in Table I.

Table I. Characteristics of the thermo-sensing films.

		Thermo-sensing films		
		Process 479	Process 480	Process 443
Film Thickness (μm)		0.42	0.51	0.5
Deposition rate ($\overset{o}{A}$ /s)		7	9.5	2.8
Solid content obtained from SIMS	x (Si)	0.06	0.04	0.11
	y(Ge)	0.67	0.71	0.88
	Z(B)	0.26	0.23	Traces ($2x10^{-5}$)
Film properties	E_a (eV)	0.21	0.18	0.345
	TCR (K^{-1})	-0.027	-0.023	-0.044
	σ_{RT} $(\Omega cm)^{-1}$	$1x10^{-2}$	$2.5x10^{-2}$	$6x10^{-5}$
	σ_0 $(\Omega cm)^{-1}$	36.46	24.55	34.85

Conductivity and noise measurements were conducted with planar structures with Ti bottom electrodes deposited on glass. The current-voltage I(U) characteristics of the structures were measured in vacuum (P = 10 mTorr) thermostat ("MMR Inc.") with electrometer ("Keithley" – 6517-A). The noise spectral density (NSD) measurements were performed with lock-in amplifier ("Stanford Research Systems" – SR 530) in the frequency range of 4 to $2x10^4$ Hz and Δf= 1Hz.

RESULTS AND DISCUSSION

Noise spectral density (NSD) is defined as $S_I(f) = [I_{noise}(f)/(\sqrt{\Delta f})]^2$, where $I_{noise}(f)$ is r.m.s. current noise, Δf = 1 Hz is a bandwidth. Noise spectra measured at room temperature are shown in Figure 1. It can be seen that these films showed different $S_I(f)$ behavior. The sample $Si_{0.11}Ge_{0.88}$:H (443) without boron showed the lowest noise while the sample $Si_{0.04}Ge_{0.72}B_{0.23}$ (480) showed the highest noise in the entire range of frequency. All samples revealed increase of noise with reducing frequency, but they have different slopes extracted from $S_I(f) \sim f^{\beta}$ approximations. The sample $Si_{0.11}Ge_{0.88}$:H (443) showed the highest slope β = 1 i.e. "classical" 1/f noise behavior, the sample $Si_{0.04}Ge_{0.72}B_{0.23}$ (480) had the lower slope β =0.4 and the sample 479 showed 2 slopes: β_1 = 0.74 in low frequencies (f< 2 $x10^2$ Hz) and lower value β_2 =0.13 in the range of frequency $f > 2x10^2$ Hz.
Interesting data were obtained from noise-temperature measurements. NSD for $Si_{0.11}Ge_{0.88}$:H sample (process 443) is shown in Figures 2 . At room temperature this sample has one slope β =

1 but increasing temperature results in more complex noise spectra, where two regions with different slopes β_1 and β_2 can be distinguished. The insert in Figure 2 shows dependence of

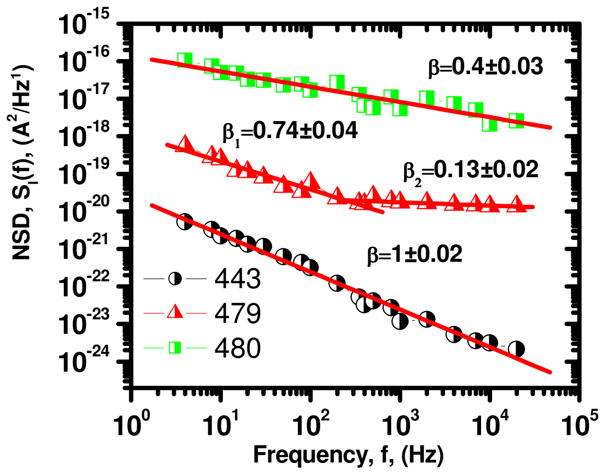


Figure 1. Noise spectra for different thermo-sensing films at T=300K : a) $Si_{0.11}Ge_{0.88}$:H (443), b) $Si_{0.06}Ge_{0.67}B_{0.26}$:H (479), and c) $Si_{0.04}Ge_{0.71}B_{0.23}$:H (480).

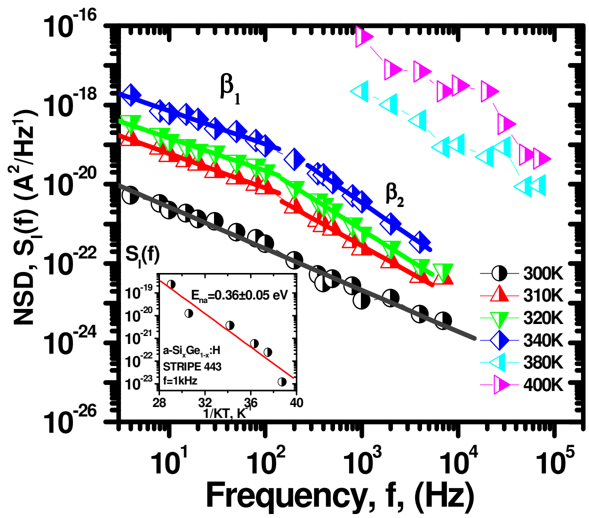
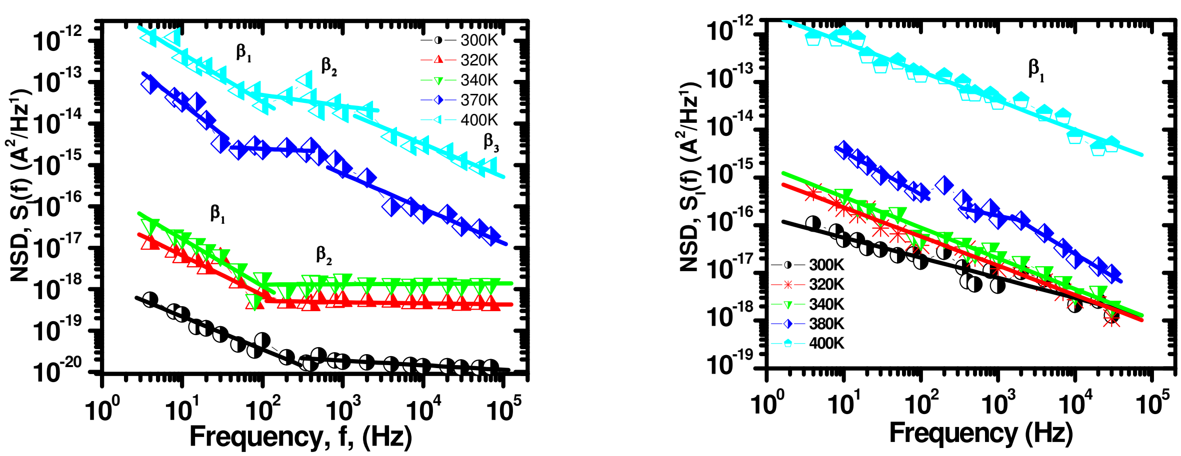


Figure 2. Noise spectra at different temperatures for the sample $Si_{0.11}Ge_{0.88}$:H (443).

noise at f=1 kHz as a function of temperature. Solid line is the best fit of the experimental points that reveals temperature activation behavior characterized by noise activation energy E_{na}= 0.36 eV. Noise spectra measured at different temperatures for other samples studied are presented in Figure 3 a) (sample $Si_{0.06}Ge_{0.67}B_{0.26}$: H, process 479) and Figure 3 b) (sample $Si_{0.04}Ge_{0.71}B_{0.23}$: H,



a) b)

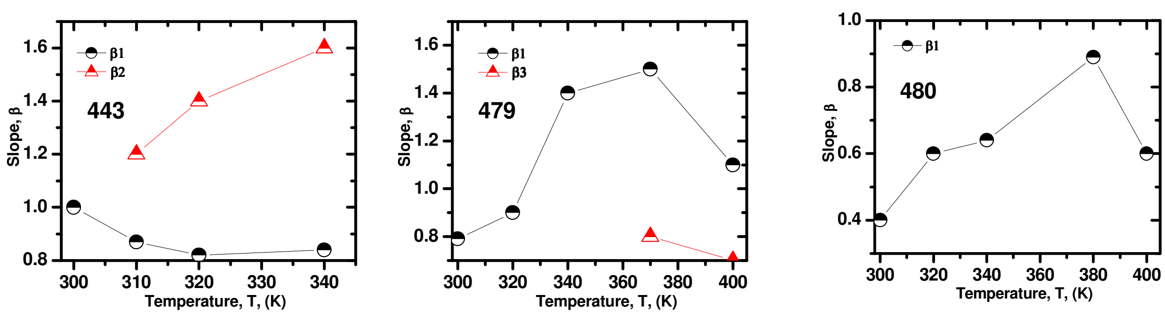
Figure 3. Noise spectra at different temperatures for the samples: a) $Si_{0.06}Ge_{0.67}B_{0.26}$:H (479), and b) $Si_{0.04}Ge_{0.71}B_{0.23}$:H (480).

process 480). In all samples studied increasing temperature causes more complex and different, depending on composition of the film, behavior of noise spectra. Thermally activated character of noise change with temperature was observed in all samples, but they demonstrated different room temperature noise and activation energy values. The values obtained are listed in Table II.

Table II. Temperature characteristics of noise at f=1 kHz.

Sample	S_I(f=1 kHz), A^2/Hz	Noise activation energy, E_{na}, eV	Conductivity activation energy, E_a, eV
$Si_{0.11}Ge_{0.88}$ (process 443)	2.2×10^{-23}	0.36±0.05	0.35
$Si_{0.06}Ge_{0.67}B_{0.26}$ (process 479)	2.1×10^{-20}	0.7±0.1	0.21
$Si_{0.04}Ge_{0.71}B_{0.23}$ (process 480)	6.3×10^{-18}	0.16±0.01	0.18

Comparing noise (E_{na}) and conductivity (E_a) activation energies presented in Table II it can be seen a close correlation between these values for the sample $Si_{0.11}Ge_{0.88}$:H (443) and $Si_{0.04}Ge_{0.72}B_{0.23}$:H (480). Although for the sample $Si_{0.06}Ge_{0.67}B_{0.26}$:H (479) noise activation energy determined in the same way as for the previous samples at $f=10^3$ Hz is remarkably larger than conductivity activation energy. It should be noted, however, that for this sample it was observed a change of noise mechanism with temperature: in the temperature range 300 K $\leq T \leq$ 340 K noise at $f = 10^3$ Hz corresponded practically to "white" noise, while at higher temperature $T >$ 340 K it became "1/f" type noise with $S_I \sim f^{-\beta}$. The correlation between E_{na} and E_a observed in two samples allows us to think that noise is due to bulk rather than interface processes. Additionally changing character of noise spectra with temperature can be revealed from temperature dependence of slopes in noise spectra. In two samples (443 and 479) noise spectra demonstrated two-three regions with different slopes. Temperature dependence of slope (s) is presented in Figure 4. Low frequency slope β_1 reduces with temperature in the sample 443 without boron and increases in the samples with boron 479 and 480. β_3 determined at higher



a) b) c)

Figure 4. β factor as a function of temperature: a) for the sample 443, b) for the sample 479 and c) for the sample 480. Solid connecting lines are guides for the eyes.

frequency than β_1 rises with temperature in the sample 443 without boron and reduces in the sample with boron 479. Low frequency slope in the samples with boron 479 and 480 show similar trend with temperature (increases, reaches maximum and decreases) differing from behavior in the sample without boron (continuous reducing and saturation with temperature).

Comparing noise spectra (normalized by current cross section area) presented in Figure 5 for the thermo-sensing film (sample 443) and for micro-bolometer fabricated with the same film it can

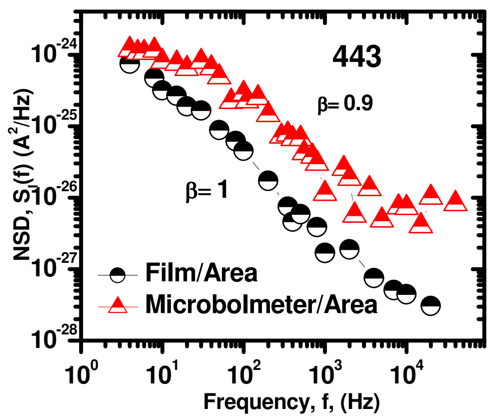


Figure 5. Comparison of noise spectra for thermo-sensing film and micro-bolometer with the same thermo-sensing film (NSD is normalized by current cross section area).

be seen that noise within the entire frequency range studied is higher for micro-bolometer than that in the same thermo-sensing film. Slopes in low frequencies $f < 10^3$ Hz have very close values. For higher frequencies $f > 10^3$Hz micro-bolometer has higher noise by about 2 orders of value. Moreover device in this region shows "white" noise, while the film shows "1/f " noise. The observed difference in noise spectra for the thermo-sensing film and the micro-bolometer with the same thermo-sensing film means an existence of additional processes inducing noise.

CONCLUSIONS

Noise spectra $S_I(f)$ have been studied for $Si_xGe_yB_z$:H thermo-sensing films used in micro-bolometers. These films were deposited by LF PECVD with variation of gas mixture composition. Strong dependence of noise spectra on composition was observed. This dependence can not be related only to conductivity difference. The measurements of noise spectra at different temperatures have revealed a thermal activated increase of noise with temperature. The correlation observed for two samples between noise and conductivity activation energies suggests that noise is due to bulk rather than interface processes. Noise observed in micro-bolometer was higher than that for the thermo-sensing film in the entire frequency region. $S_I(f)$ for micro-bolometer structure showed difference in slopes (β factors) in comparison with that for the thermo-sensing film. Both observations allow us to think that additional processes induce noise in the device structure.

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