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Thin Solid Films 515 (2007) 7607 – 7610
www.elsevier.com/locate/tsf

Fabrication and performance comparison of planar and sandwich structures of micro-bolometers with Ge thermo-sensing layer

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Available online 16 January 2007

Abstract

Two types of micro-bolometer structures were fabricated with the same materials and fabrication process. The structures are labeled planar and sandwich types. Their performance was measured and a comparison was performed among these structures. Our results show that the sandwich type structure behaves better in terms of the voltage and current responsivity, but shows 2 to 3 orders of magnitude higher $1/f$ noise levels. In spite that the sandwich configuration shows a lower response time constant than that of the planar device, the noise level makes the detectivity of both devices practically the same.

Keywords: Amorphous materials; Germanium; Silicon

1. Introduction

The development of high performance bolometers in conjunction with the silicon IC fabrication technology with the incorporation of surface micromachining techniques has paved the way for low cost and large format IR imaging devices. In a high performance micro-bolometer, the material used as thermo-sensing layer must meet at least the following requirements: a high value of the temperature coefficient of resistance (TCR), coefficient which is defined as $\mathrm{TCR}=\alpha=(1/R)(\mathrm{d}R/\mathrm{d}T)$, low noise, and compatibility with standard IC fabrication processes. Among the currently used materials in bolometer fabrication vanadium oxide, metals, and amorphous and polycrystalline semiconductors can be mentioned [1–4]. Even though good results have been achieved with those materials, none of them can be considered as the optimum one. Amorphous semiconductors – which have showed a high value of TCR – are fully compatible with the silicon technology. However, intrinsic amorphous semiconductors have a very high resistance which often results in a mismatch with the input impedance of the read-out circuit. For room temperature operation amorphous silicon (a-Si:H) has been employed in commercial applications; but because of its undesirable high resistivity, boron doping has been used in order to reduce the resistivity of these films. However by doing this, there is a decrease in its activation energy (E_a) and consequently, a decrement on the TCR [1]. In our previous work [4] amorphous germanium and silicon germanium films obtained by PECVD were employed in the fabrication of micro-bolometers, providing high activation energy and acceptable resistivity without doping. In this paper we report the comparative study of planar and sandwich configurations for an un-cooled micro-bolometer with Si_xGe_y:H as the thermo-sensing layer.

2. Experimental

The micro-bolometer sandwich structure fabrication process is as follows. A 200 nm-thick SiO_2 layer was thermally grown on a c-Si wafer and a 2.5 μm-thick aluminum layer was deposited by e-beam evaporation over it. Aluminum is used as the sacrificial layer and after patterning it a layer of 0.8 μm-thick of SiN was deposited by low frequency PECVD over it. The SiN layer is then patterned by reactive ion etching (RIE) and the aluminum sacrificial layer is removed in order to form a SiN bridge. After that, a 200 nm-thick titanium layer was deposited by e-beam evaporation and patterned in order to form the bottom electrode and contact pad of the device. A 0.5 μm-thick thermo-sensing Si_xGe_y:H layer was deposited over the electrode by low frequency LF PECVD technique at a rf frequency

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doi:10.1016/j.tsf.2006.11.172

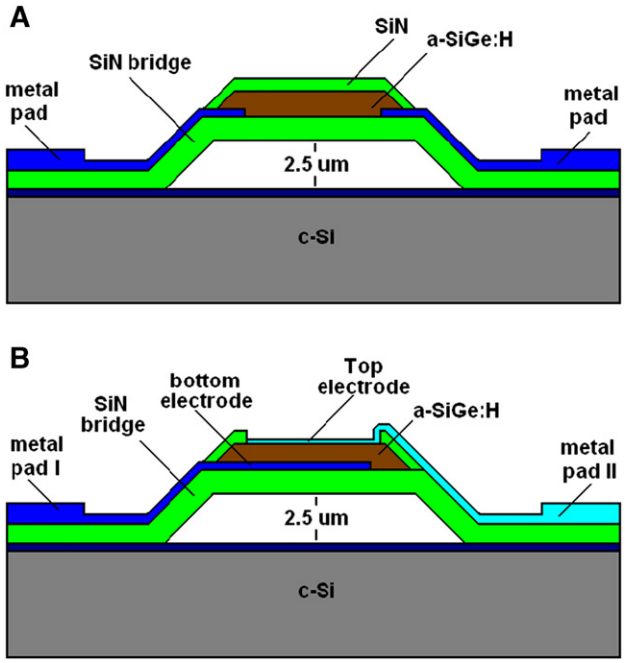

Fig. 1. Micro-bolometer structure with A) planar and B) sandwich contacts.

f=110 kHz, temperature T=300 °C, power W=350 W and pressure P=0.6 Torr. The Si_xGe_y:H film was deposited from a $SiH_4+GeF_4+H_2$ mixture with gas flows: Q_{SiH_4}=25 sccm, Q_{GeF_4}=25 sccm, Q_{H_2}=100 sccm. This results in a Ge content

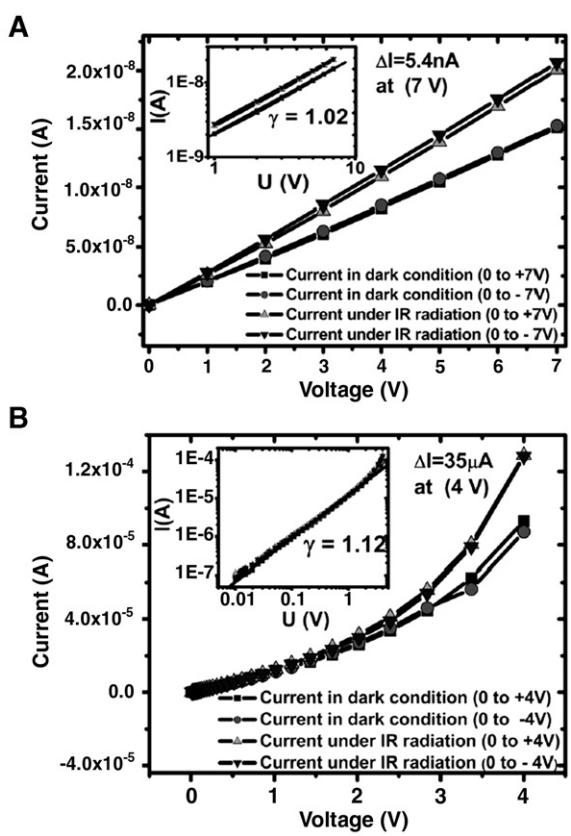

Fig. 2. $I(U)$ characteristics of micro-bolometer A) planar and B) sandwich structures.

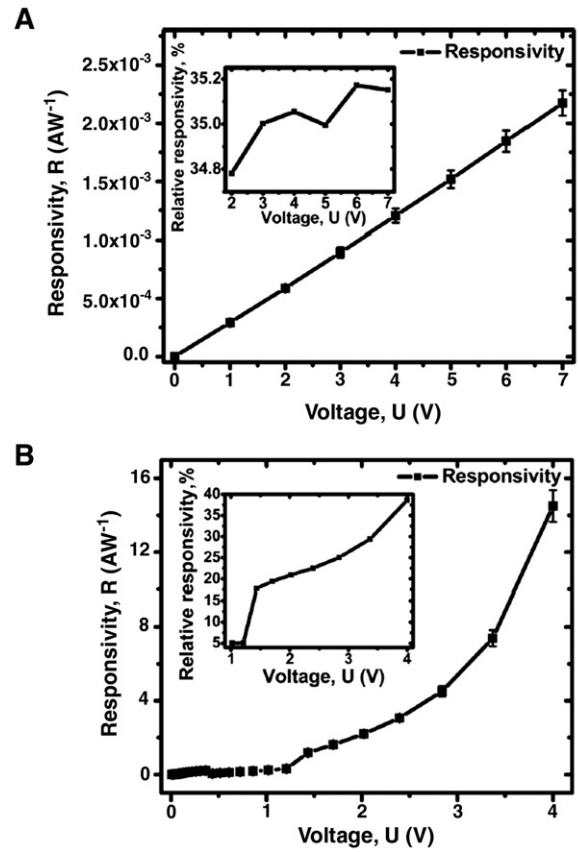

Fig. 3. Responsivity of micro-bolometer A) planar and B) sandwich structures.

in solid phase Y=0.98. Details of the Si_xGe_y:H characterization are found in [4]. The thermo-sensing layer was covered by a SiN layer for protection and a window was open on it by RIE, then a 10 nm-thick titanium layer was deposited by e-beam evaporation and patterned in order to form a top electrode, an additional 200 nm-thick Ti layer was deposited and patterned in order to form the pad and the connection line that makes contact to the thin top electrode. The active area of the thermo-sensing layer is $A_b=70\times66$ μm^2. The micro-bolometer planar structure fabrication process is similar to the sandwich structure fabrication process, but in this case both electrodes are placed under the thermo-sensing Si_xGe_y:H layer and such layer is covered by a SiN layer for protection. A sketch of the planar structure is shown in Fig. 1A and a sketch of the sandwich structure is shown in Fig. 1B.

The performance of the devices was determined through the measurement of $I(U)$ characteristics in dark and under IR illumination from a "Globar" source, which provides an intensity $I=5.3\times10^{-2}$ W/cm^2 on the sample surface and its spectrum falls in the range λ=2–14 μm. The $I(U)$ measurements were performed at room temperature with the use of an electrometer ("Keithley" — 6517-A) and the applied voltage was varied from 0 to 4 V. The responsivity was calculated from $I(U)$ results. Noise measurements in the micro-bolometers were realized using a lock-in amplifier ("Stanford Research Systems" — SR530). The noise of the system and the total noise (system+cell noise) were measured separately, and a subtraction of both was made in

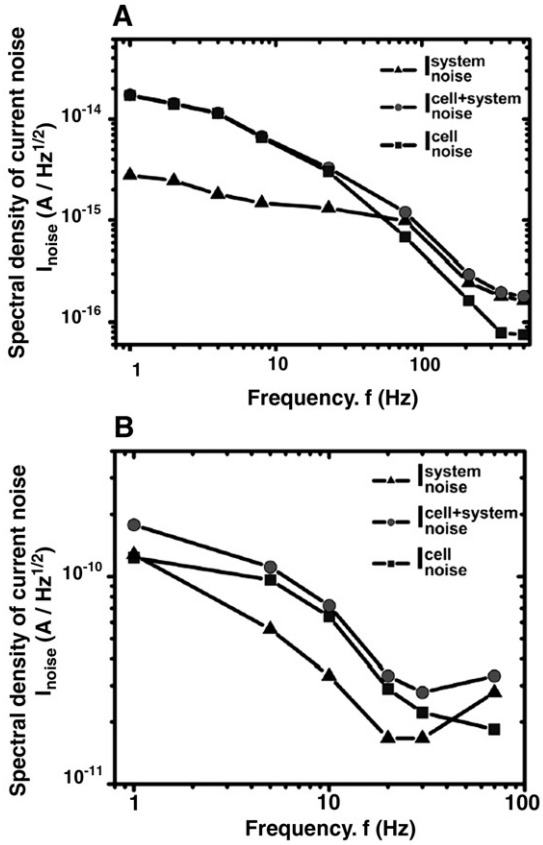

Fig. 4. Spectral density of current noise, $I_{\mathrm{noise}}^{\mathrm{cell}}(f)$ as a function of frequency of the micro-bolometer with A) planar and B) sandwich structures.

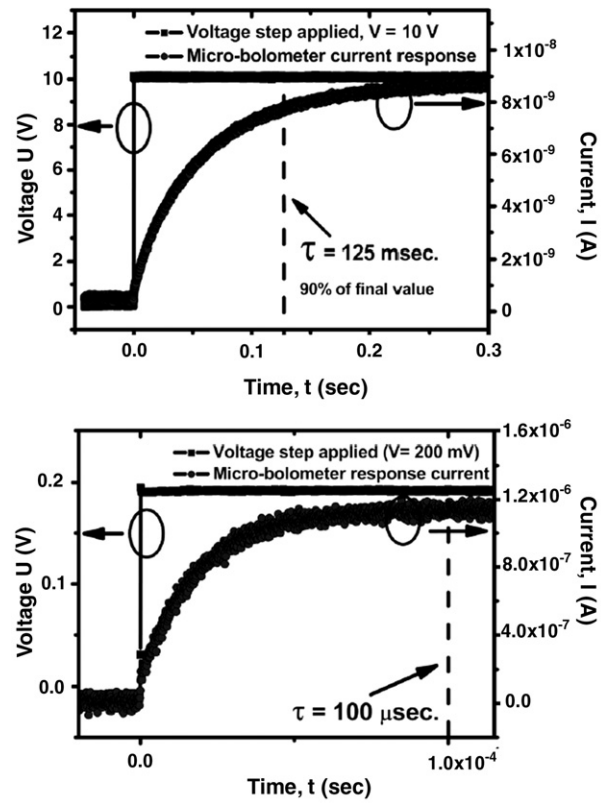

Fig. 5. Response time of the micro-bolometer A) planar and B) sandwich structures.

order to obtain the noise of the device. The detectivity was calculated from $I(U)$ and noise results. The response time constant defined at 90% level of the steady state was determined by applying a voltage pulse to the bolometer and measuring the current behavior. The measurements were performed in vacuum thermostat at a pressure $P \approx 10$ mTorr.

3. Results and discussion

The configurations used for comparison of un-cooled micro-bolometer are shown in Fig. 1. Both have the same dimensions, area of the thermo-sensing layers, materials for bridge construction and metal contacts. The main difference in these structures is the configuration of the electrodes and, consequently, a difference in the direction of the current flow, which goes along the thermo-sensing film in the planar configuration and perpendicular to the thermo-sensing film for the sandwich structure. This results in a significant lowering of the device resistance for the sandwich structure in comparison with the planar configuration.

Current–voltage, $I(U)$ characteristics in dark and under IR illumination are shown in Fig. 2 for both configurations studied. Linear $I(U)$ characteristics are observed for planar configuration as it is demonstrated in the inset in Fig. 2A. In the sandwich structures $I(U)$ shows slight deviation from linear behavior, as can be seen in Fig. 2B and the inset, which suggests the influence of the contacts.

Table 1
Comparison of the characteristics of micro-bolometers

Thermo-sensing layer	E_a, eV	TCR, α K^{-1}	Pixel area, A_b, μm^2	Thermal time constant, ms	Pixel resistance, R_b, Ω	Voltage responsivity, $\Re_U$, V W^{-1}	Current responsivity, $\Re_I$, A W^{-1}	Spectral response, μm	Detectivity, D^* cm Hz$^{1/2}$ W^{-1}	Ref.
a-Si:H,B	–	0.028–0.039	48×48	11	3×10^7	10^6	–	5–14	–	[1]
$Ge_xSi_{1-x}O_y$	–	0.048	50×50	13	–	1×10^5	–	10	6.7×10^8	[3]
a-$Si_{1-x}Ge_x$:H	0.34	0.043	70×66	0.1	$(1–30)\times10^5$	2×10^5	0.3–14	2–14	$(1–40)\times10^8$	Sandwich structure
a-$Si_{1-x}Ge_x$:H	0.34	0.043	70×66	125	5×10^8	7.2×10^5	2×10^{-3}	2–14	2.5×10^9	Planar structure

Current responsivity R_I is defined as $R_I=(I_{IR}-I_d)/I_0$, where, I_{IR} is the current under IR illumination, I_d is the dark current, and I_0 is the incident IR intensity. R_I is significantly larger in the sandwich structures with respect to the planar one. This behavior is shown in Fig. 3, in which a faster and no-linear increase with U in R_I in the sandwich structure is observed, in comparison with the planar structure.

The current noise spectral density (NSD) $I_{noise}^{cell}(f)$ form for both configurations is shown in Fig. 4, where $I_{noise}^{cell}(f)=I_{noise}^{cell+system}(f)-I_{noise}^{system}(f)$, $I_{noise}^{cell+system}(f)$ is the NSD measured in the micro-bolometer cell together with the measuring system and $I_{noise}^{system}(f)$ is the NSD measured in the system without the micro-bolometer cell. The large difference between the NSD $I_{noise}^{cell+system}(f)$ observed among the two structures, is also due to different circuits used to measure it for matching the output resistance of each cell with measuring instrument. $I_{noise}^{cell}(f)$ values observed for planar configuration are around 4 orders of magnitude less that that of the sandwich structure, which means that noise level, depends on the device configuration. From the measured responsivity and noise we calculate detectivity D^* for both structures. The obtained values are listed in Table 1 and compared with data reported in literature.

Response time characterization of the devices has been performed following the technique described in Ref. [5]. The measured current transient time τ, is the characteristic time for switching conductivity from dark state to steady state of the thermo-sensing layer under illumination, Fig. 5 shows τ of both devices. In the case of ohmic current voltage characteristics τ is determined by temperature transient of the thermo-sensing layer and depends on effective thermo-conductivity and thermal capacitance. The result presented in Fig. 5 was obtained in ohmic regime (see Fig. 2). $I(U)$ characteristics for sandwich structures under $U\geq 3$ V showed non-ohmic behaviour, however IR sensing in non-linear $I(U)$ regime is a subject for further study. The experimental τ values are $\tau=125$ ms for planar and $\tau=0.1$ ms for sandwich structures.

4. Conclusions

We have compared the performance un-cooled micro-bolometers fabricated in planar and sandwich configurations with the same fabrication process and materials. From the results summarized in Table 1 the following can be stressed: the sandwich structure shows a pixel resistance lower by 2–3 orders of magnitude to that of the planar structure, therefore it can be easily matched with read-out circuitry; current responsivity for the sandwich structure is about 2–3 higher than the planar structure, while voltage responsivity is approximately the same. In spite of these advantages, the current noise density is higher by 2–3 orders of magnitude for the sandwich structures than that of the planar devices; as a consequence, the detectivity for both structures is approximately the same. Finally, the response time constant is about 3 orders less for the sandwich structures with respect to the time observed in the planar type of devices.

Acknowledgments

The authors acknowledge the support of this research by CONACyT project No. 42367 (CIAM-2002).

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