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Characterization of Uncooled Poly SiGe Microbolometer for Infrared Detection *

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An uncooled poly SiGe microbolometer for infrared detection has been fabricated and characterized. The poly SiGe thin film is deposited by ultrahigh vacuum chemical vapour deposition (UHVCVD) system and its structural properties are characterized by Rutherford backscattering spectrometry (RBS) and Raman. The dependences of the temperature coefficient of resistance on operation temperature and on annealing temperature have been investigated. A leg-supported microbridge is used to decrease the thermal conductance of microbolometer with the silicon micromachining technique. The results show that at a chopping frequency of 15 Hz and a bias voltage of 5 V, the maximum detectivity of 8.3×10^8 *cm* $Hz^{1/2}$*/W is achieved with a thermal response time of 16.6 ms.*

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In recent years, much attention has been paid to uncooled infrared (IR) detectors for their wide applications such as remote sensing, alarm, biomedical thermograph and gas detection.[1−4] There are basically three types of uncooled IR detector: microbolometer, pyroelectric and thermopile type. We have chosen microbolometer type detector for our present research because its responsivity is much higher than that of thermopile detector, and it is generally easier to fabricate than pyroelectric detector.

The important considerations of choosing active material for microbolometer include high temperature coefficient of resistance (TCR), low noise and compatibility with the integrated circuit (IC) fabrication. A wide variety of materials have been used as active element for microbolometer. Vanadium oxide (VO_x) is the most widely used due to its high TCR of $-2 \sim -3\%/^\circ C$ and its low temperature process.[1] The main drawback of VO_x is that it is not a standard material in the IC fabrication. Although amorphous silicon carbide (a-SiC_x) with a high TCR of $-4 \sim -6\%/^\circ C$ is an IC compatible material,[2] it requires a high annealing temperature of about 1000°C to achieve stability of microstructures, which is unsuitable for post-CMOS processing since such a high temperature must have destroyed the readout IC. Another commonly used IC compatible material is the boron doped amorphous silicon (a-Si:B) which has an attractive TCR of $-2 \sim -8\%/^\circ C$, while its excess $1/f$ noise badly compromises the TCR.[3]

In this Letter, we present a microbolometer with poly SiGe resistor as active element. Since the melting point of SiGe alloy is lower than that of Si, one advantage of poly SiGe is that it requires lower thermal budget for crystallization, grain growth and dopant activation than poly-Si.[5] Thus, the use of poly SiGe can reduce processing temperature. In addition, the poly SiGe provides a comparable low thermal conductivity which increases responsivity of microbolometer. The thermal conductivity of poly $Si_{0.7}Ge_{0.3}$ is a factor of four lower than that of poly-Si.[6]

The performance of microbolometer is expressed by responsivity R_v and detectivity D^*. The responsivity characterizes the microbolometer response to the IR radiation. It is defined as the output voltage divided by the input radiant power falling on the microbolometer surface, and is given by[7]

$$R_v = \frac{|\alpha|\eta V R_b R_L}{G(R_b + R_L)^2\sqrt{1+4\pi^2 f^2\tau^2}}, \tag{1}$$

where α is the TCR defined as $\alpha = (1/R_b)(dR_b/dT)$, η is the fraction of the incident radiation absorbed, V is the bias voltage, R_b is the microbolometer resistance, R_L is the load resistance, G is the total thermal conductance to the substrate, f is the radiation modulation frequent, and τ is the thermal time constant.

The electrical noise is important in determining the detectivity of a microbolometer. The detectivity is a figure of merit that measures the signal-to-noise ratio and normalizes the performance of the detector with respect to the detector size, and is given by[7]

$$D^* = R_v\sqrt{A_d \Delta f}/V_n, \tag{2}$$

where A_d is the microbolometer area, Δf is the frequent bandwidth, and V_n is the total noise voltage of the microbolometer.

The voltage noise includes Johnson noise V_J due to the thermal agitation of charge carriers, $1/f$-noise $V_{1/f}$ due to trapping and detrapping mechanisms and surface state scattering, and temperature fluctuation

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noise V_{th} arising from the fluctuations in the heat exchange between active element and heat sink. The total noise voltage V_n is the rms of these noise components and can be given by

$$V_n = \sqrt{V_J^2 + V_{1/f}^2 + V_{th}^2}. \quad (3)$$

The scanning electron microscopic (SEM) picture of the poly SiGe microbolometers is shown in Fig. 1. The poly SiGe thin film resistor, i.e., the active element of microbolometer, is suspended and supported by thermally isolated legs which reduce the thermal conductance and enhance the temperature increase caused by absorption of the IR radiation. The microbridge is fabricated by using the silicon micromachining technique. The IR absorber on the surface is a composite membrane made of SiO_2 and Si_3N_4, which can typically achieve an average absorptivity of 20%–30% in the spectral region of 8–14 μm.[8]

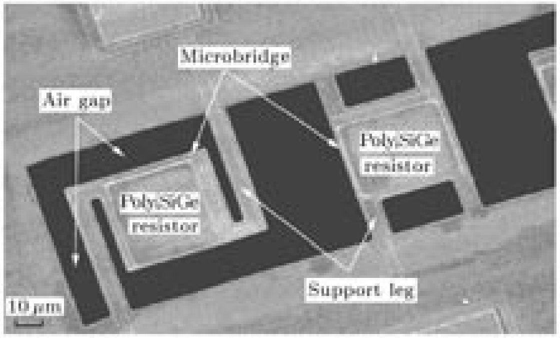

Fig. 1. SEM photograph of poly SiGe microbolometer with a two- or four-leg-supported microbridge.

The fabrication process starts with a 3-inch double side polished p-type (100) silicon wafer with 300 nm thermal oxide silicon and 200 nm low pressure chemical vapour deposition (LPCVD) Si_3N_4. The major process steps are shown in Fig. 2 and described as follows. An ultrahigh vacuum chemical vapour deposition system (UHVCVD) is used to deposit the poly SiGe thin film, with pure SiH_4 and GeH_4 as the source gases. The base pressure is 1×10^{-7} Pa. The deposition is carried out at a temperature of 550°C and a chamber pressure of 2.5×10^{-2} Pa, with flow of 15.0 sccm for SiH_4 and 4.4 sccm for GeH_4. The growth rate is about 45 Å/min. After deposition, poly-SiGe thin film is doped by ion implantation with a low boron dose of $4 \times 10^{13}\,\mathrm{cm}^{-2}$, obtaining the desired resistivity and TCR [Fig.2 (a)]. The plasma enhanced chemical vacuum deposition (PECVD) SiO_2 of 200 nm is deposited on to the poly SiGe and patterned to form the first layer of the IR absorber. The support leg of microbolometer also acts as electrical contact and must be highly doped. This is achieved by implanting a boron dose of $5 \times 10^{15}\,\mathrm{cm}^{-2}$ and subsequently annealing at 650°C for 1 min in the N_2 ambient by rapid thermal annealing (RTA) reactor. The entire poly SiGe resistor is patterned by reactive ion, etching using SF_6 as reactive gas. The 200 nm PECVD Si_3N_4 is deposited as the second layer of the IR absorber [Fig. 2(b)]. The contacts of the electrodes are patterned and 1.0 μm aluminium is sputtered, patterned and metallized. Slits around the poly SiGe resistor and backside windows are opened by dry and wet, etch [Fig. 2(c)]. Finally, bulk silicon under poly SiGe resistor is removed by anisotropic, etching in advanced tetramethyl ammonium hydroxide (TMAH) solution [Fig. 2(d)].[9] The SEM picture of some microbolometers in Fig. 1 shows that the microbridge is suspended and flat, suggesting the stress in composite membrane is well compensated.

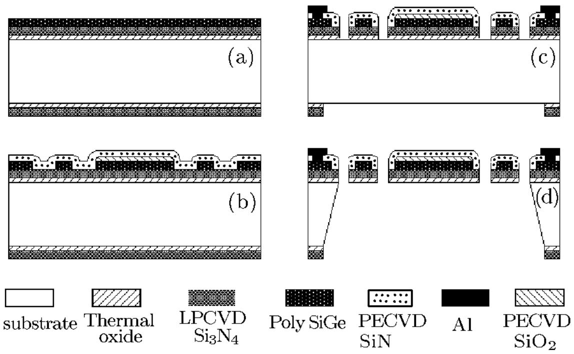

Fig. 2. Process flow of poly SiGe microbolometers.

The prepared poly-SiGe thin film has a Ge mole fraction of 0.29 by Rutherford backscattering spectrometry (RBS) measurement. Figure 3 shows the typical Raman spectra of as-deposited poly-SiGe. We can clearly see the three Raman peaks (longitudinal optical phonon) representing the Si-Si, Si-Ge and Ge-Ge phonon modes locate at 288, 405 and 501 cm^{-1}, respectively.

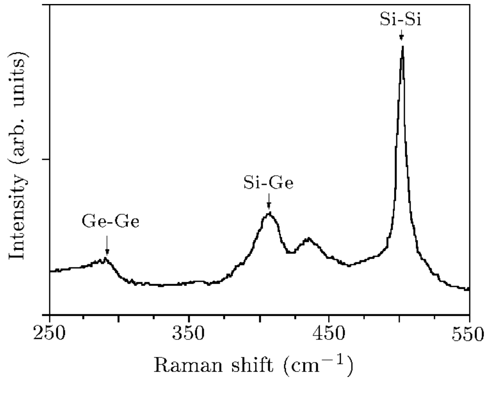

Fig. 3. Raman spectra of the poly SiGe thin film.

Sheet resistance R_s of the poly SiGe is measured with four-point probe. Figure 4 shows the dependence of operation temperature T on R_s and TCR. For the poly SiGe with boron doping dose of $4 \times 10^{13}\,\mathrm{cm}^{-2}$ and annealing at 650°C, R_s is 0.35 MO, and TCR is $-1.91\%/\mathrm{K}$ at 296 K. The value of $\log R_s$, as well as TCR, varies linearly with $1/T$. An activation energy of 0.145 eV is deduced from the slope of $\log R_s \sim 1/T$.

In order to investigate the effects of the annealing temperature on the resistance and TCR of poly SiGe, we anneal the samples with boron doping dose of $4 \times 10^{13}\,\mathrm{cm}^{-2}$ at different temperatures ranging from 650°C to 1050°C for 1 min in N_2 ambient by RTA reactor. It is indicated in Fig. 6 that both resistance and TCR decrease approximately linearly and not sharply until the annealing temperature reaches 950°C, then both drop distinctly. This may be due to the recrystallization at higher annealing temperature, forming a large crystalline and reducing the total grain boundary area available to trap carriers in the poly SiGe. Thus, the activation energy must be reduced strongly, which results in a distinct drop of resistance and the TCR at 1050°C. Figure 5 also indicates that 650°C is enough to activate the boron dopant in poly SiGe, which is helpful to reduce the processing temperature.

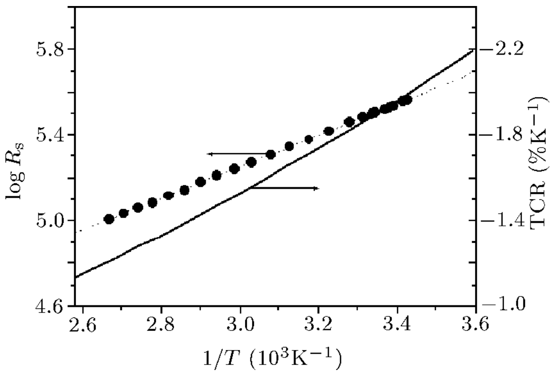

Fig. 4. Dependences of the resistance and temperature coefficient of resistance (TCR) on the operation temperature.

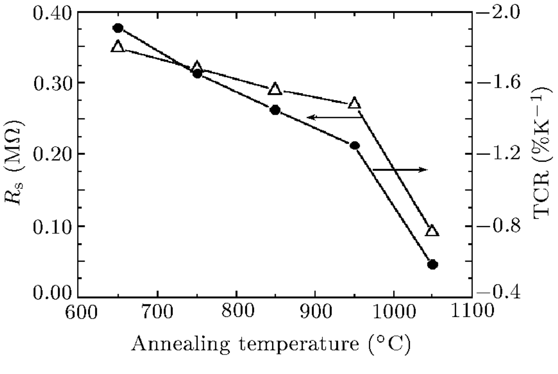

Fig. 5. Dependences of the resistance and TCR on the annealing temperature.

The noise voltage and responsivity of the poly SiGe microbolometer are measured in atmosphere at an operation temperature of 296 K. The microbolometer is connected in series to a dc voltage source and to a load resistance equal to the microbolometer resistance. It is then exposed to the radiation of a black body at 773 K. An optical filter is used to reduce the spectral region of 8–14 μm. The incident radiation is modulated by a mechanical chopper, and the signal is measured using an SR510 lock-in amplifier.

Figure 6 shows the noise voltage as a function of the chopping frequency at a bias voltage of 5 V. It is well known that the Johnson noise voltage of per unit bandwidth is independent of chopping frequency. Here the calculated V_J is about $45\,\mathrm{nV/Hz}^{1/2}$. Assuming that the temperature fluctuation noise is negligible, we note that the $1/f$-noise is dominant at low frequency ($f < 100\,\mathrm{Hz}$) and is comparable to the Johnson noise until the chopper frequency reaches 150 Hz, and the rest is dominated by the Johnson noise. The $1/f$-noise of poly SiGe is much lower than that of a-Si:B.[3]

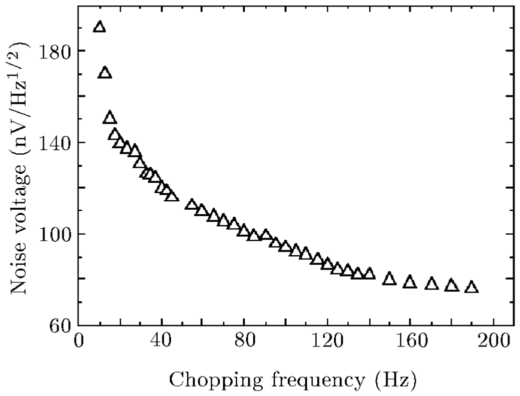

Fig. 6. Dependence of the noise voltage on the chopping frequency.

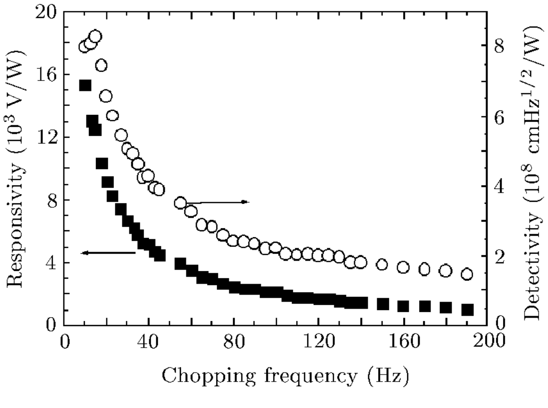

Fig. 7. Dependences of the responsivity and detectivity on the chopping frequency.

Figure 7 shows the responsivity and detectivity as a function of the chopping frequency at a bias voltage of 5 V. It is indicated that the poly SiGe microbolometer has a high responsivity that depends strongly on frequency, decreasing from over 15000 V/W at 10 Hz to about 1000 V/W at 200 Hz. The maximum detectivity of 8.3×10^8 cm $\mathrm{Hz}^{1/2}$/W is achieved at 15 Hz. The 3 dB cut-off frequency of responsivity is 60 Hz. Therefore, the thermal response time, reciprocal cut-off frequency, is 16.6 ms.

The experimental results show that the poly SiGe microbolometer is easier to fabricate and has a high performance which is adequate for IR thermal imaging applications. It should be contributed to the low deposition and annealing temperature of poly SiGe thin film. The poly SiGe microbolometer seems to have promising applications in monolithic infrared detector.

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