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Noise reduction of a-$Si_{1-x}Ge_xO_y$ microbolometers by forming gas passivation

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Abstract

We report the reduction of noise voltage power spectral density (PSD) of amorphous $Si_{1-x}Ge_xO_y$ microbolometers by forming gas passivation. The microbolometers fabricated from $Si_{1-x}Ge_xO_y$ were passivated in a rapid thermal annealing chamber in the presence of forming gas at 250 °C with different intervals of time starting from 0.5 h to 8 h. The noise voltage PSD was measured at different bias currents before passivation and after different interval of passivation time. It was found that the noise voltage PSD of the bolometers decreased as the passivation time increased. The 1/*f*-noise coefficient (K_f) was decreased from 7.54×10^{-7} to 2.21×10^{-10} after 8 h of forming gas passivation performed at 250 °C.

Keywords: Bolometer; Forming gas passivation; Noise; Annealing;; Silicon germanium oxide

1. Introduction

A bolometer is a thermal detector whose resistance is changed by the heating from absorbed radiation. Noise limits set the lower level of sensitivity of the detector. The bolometer's performance is degraded by six possible sources of internal noise [1]. The primary noise sources are Johnson noise, shot noise, generation-recombination (g-r) noise, flicker noise (1/*f*), temperature fluctuation noise, and background radiation noise. The bolometer's figures of merits (detectivity, noise equivalent power) are limited by the noise behavior of the bolometer [2] and 1/*f*-noise is a major limiting factor in the performance of a microbolometer [3].

Poly SiGe [3], amorphous SiGe alloys [4] and amorphous $Ge_xSi_{1-x}O_y$ [5,6] are attractive materials of SiGe family for bolometers mainly because of their high temperature coefficient of resistance, although they exhibit 1/*f*-noise like all materials used in microbolometers. Ahmed et al. [5] reported the limitation of the performance by excess 1/*f*-noise for amorphous $Ge_xSi_{1-x}O_y$ bolometers. Garcia et al. [4] used mixture of SiH_4+ GeH_4 by low frequency low pressure chemical vapor deposition technique to deposit a-$Si_{1-x}Ge_x$:H,F. They also used a-Si_3N_4 to passivate the a-$Si_{1-x}Ge_x$:H,F layer. In this case, hydrogen is incorporated during the deposition process. When a-$Si_{1-x}Ge_xOy$ is deposited typically by reactive radio frequency (rf) magnetron sputtering, hydrogen is not incorporated into the system. So in this work, the post-deposition passivation with forming gas is investigated. Garcia et al. experienced lower detectivity (2.6×10^6 cm $Hz^{-1/2}$ W^{-1}) because of relatively high 1/*f*-noise. NASA/Goddard Space Flight Center in collaboration with the University of Wisconsin [7] has reported that by increasing the Si or Ge thermistor's thickness the 1/*f*-noise can be reduced significantly. This would indicate a volumetric dependence of the 1/*f*-noise, rather than a dependence on surface states. But increasing the thermistor thickness will add thermal mass and it will make the thermal time constant of the detector larger.

In earlier work [2], the authors found the presence of high 1/*f*-noise in the $Si_{1-x}Ge_xO_y$ thin films. If this noise can be reduced then the detector's performance can be improved significantly. In this work, we are reporting the reduction of the noise voltage power spectral density (PSD) by forming gas passivation.

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2. Experimental details

Fig. 1(a) and (b) shows the cross sectional view and a scanning electron micrograph of the completed device. The depositions of different layers other than the aluminum and polyimide were done by a rf magnetron sputtering system equipped with a turbo pump and three-inch target holder. Prior to sputtering, the process chamber was evacuated to $\sim 4\times10^{-4}$ Pa by the turbo pump. Sputtering was done at 1.33 Pa pressure. In fabricating the bolometer, lift off technique was used rather than using chemical etching because of its simplicity for patterning all the films other than the polyimide.

The fabrication of the bolometer starts by depositing 400 nm of silicon nitride layer by rf magnetron sputtering on a cleaned lightly doped p-type silicon wafer. This layer of silicon nitride served as the electrical insulation for the substrate and would withstand all the solvents used in next fabrication steps. Then a 400-nm-thick layer of aluminum was deposited by thermal evaporation and patterned. This aluminum layer would serve as a mirror for reflecting the infrared rays and form the basis of an optically resonant cavity. Then a sacrificial layer of photo definable polyimide PI-2737 from HD Microsystems was spin coated, patterned by conventional photolithography and wet etching process, and cured in the convection oven to get a thickness of 2.2 μm. A 200-nm-thick silicon nitride layer was deposited and patterned. This silicon nitride layer would form the bottom layer of a sandwich structure for the microbolometer thermometer. Silicon nitride was chosen for this case because silicon nitride is known to passivate silicon [8], although in this work the author's did not observe any significant effect of

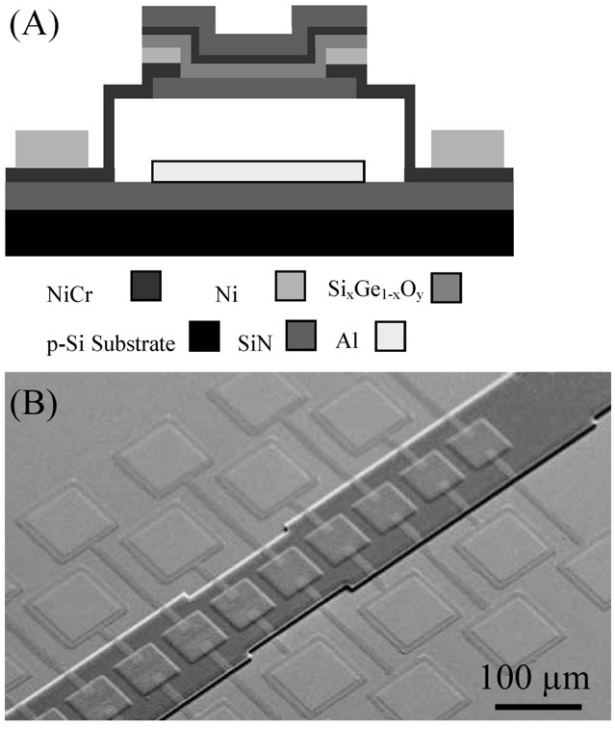

Fig. 1. $Si_{1-x}Ge_xO_y$ microbolometer (A) cross sectional view (B) SEM micrograph after fabrication.

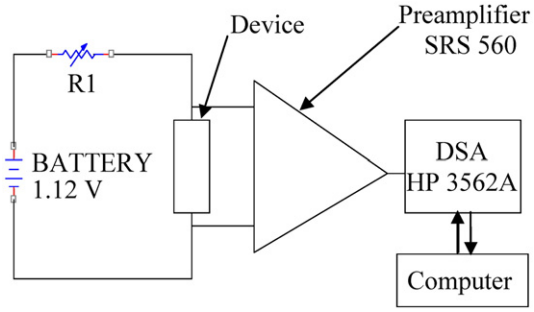

Fig. 2. Schematic for the noise measurement setup.

passivating the $Si_{1-x}Ge_xO_y$ sensing layer with silicon nitride. Next, a 140-nm-thick NiCr electrode arm was deposited and patterned. NiCr has low thermal conductivity, which is attractive in providing thermal isolation of the microbolometer thermometer from the substrate. In order to form an Ohmic contact with the p-type $Si_{1-x}Ge_xO_y$, a 50-nm-thick Ni film was deposited on top of NiCr arm and patterned to form the contact. Then, the sensing layer of 200-nm-thick $Si_{1-x}Ge_xO_y$ was deposited in an $Ar:O_2$ environment from a compound target of $Si_{1-x}Ge_x$. Next, a 14-nm-thick NiCr absorber and 200 nm-thick silicon nitride layers were deposited and patterned. Finally, a 300-nm-thick Ni bond-pad-layer was deposited on top of NiCr for bonding the device ultrasonically. At this point, the bolometer fabrication was complete. The sacrificial polyimide under the bolometer was not removed for the sake of simplicity in device fabrication. The microbolometer represents a standard design used by our research group. The details of the detection characteristics of fully micromachined microbolometers has been published elsewhere [9].

To observe the effect of forming gas annealing at different intervals of time on the noise voltage PSD of the devices, the noise voltage PSD was measured before the passivation, at the end of each interval of passivation time tracking individual devices. Four devices namely ssl3, slt1, srb4 and slb1 having resistance of 15 kΩ, 70 kΩ, 65 kΩ and 70 kΩ respectively were tested for this purpose. These four devices were fabricated on same substrate. The noise of the devices was measured inside a shielded probe station in dark and at room temperature. Fig. 2 shows the schematic of noise measurement setup. A low noise voltage preamplifier, SRS model 560, with a gain of 193 was used to amplify the noise voltage PSD from the device. The metal film resistor R1 in Fig. 2 placed in series with the device under test to limit the bias current and had a value in the MΩ range. This resistance value was varied to obtain the bias currents (I_b) of 0.85 μA, 0.6 μA, 0.3 μA, 0.1 μA and 42 nA to the bolometer circuit. A NiCd battery of 1.12 V was used to provide a low noise bias to the circuit. A Hewlett Packard model 3562A dynamic signal analyzer (DSA) was used to measure the noise voltage PSD and record the spectra. The noise voltage PSD was recorded over the frequency range of 1 Hz to 100 kHz. The current–voltage characteristics were measured by placing the device in dark inside the same shielded probe station and using a Hewlett Packard HP 4155B semiconductor parameter analyzer. For devices slt1, srb4 and slb1 the noise voltage PSD was measured before passivation and after 0.5 h, 1 h, 2 h, 3 h,