Electronic Supplementary Information

Thermoresistive properties of p-type 3C-SiC nanoscale thin films for high-temperature MEMS thermal-based sensors

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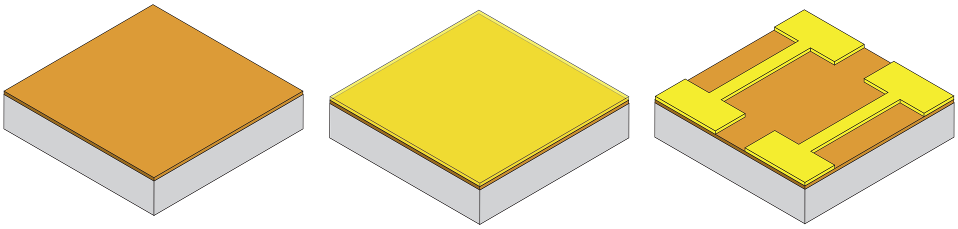
1. Fabrication of p-3C-SiC on SiO_2 substrate

1.1 Fabrication of p-3C-SiC resistors on Si substrates

(a) Growth of p-3C-SiC on Si (b) Coating photoresist (PR) (c) Parterning PR



(d) Etching SiC (e) Deposition of aluminum (f) Etching aluminum

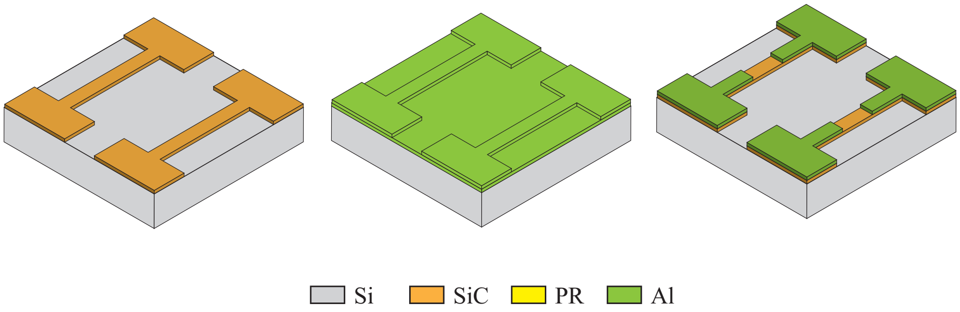
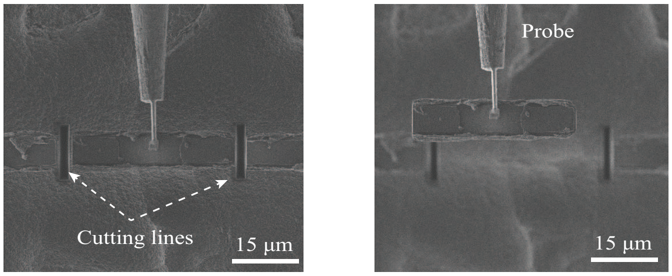


Figure 1: Fabrication processes of SiC resistors on Si (not to scale).

We fabricated the SiC resistors on Si substrates utilizing standard photolithography and dry edtching processes[1,2]. In the first photolithography process, the photoresist was coated and then patterned using a mask, Fig. 1(a,b,c). Next, the SiC was etched using HCl and O_2 active gases, Fig. 1(d). A 300-nm thin aluminum layer was deposited (Fig. 1(e)), followed by the second photolithography process. Finally, the aluminum layer was etched to form the SiC resistors and their electrodes, Fig. 1(f).

1.2 Cutting and transferring SiC structures using a Focused Ion Beam (FIB)

We first used a Focused Ion Beam tool to remove the SiC resistors from the Si substrate, Fig. 2(a). We then employed a micro probe to transfer the SiC resistors onto the glass substrate (SiO_2) which was deposited with aluminum electrodes, Fig. 2(b). The SiC resistors were then fixed on the insulation substrate by a deposited tungsten layer (W), Fig. 2(c). Figure 2(d) shows the SEM image of the p-3C-SiC/SiO_2 platform after the transferring process.


(a) Cutting the SiC resistors
(b) Transferring the SiC resistors

(c) Deposition of tungsten
(d) p-3C-SiC on SiO_2

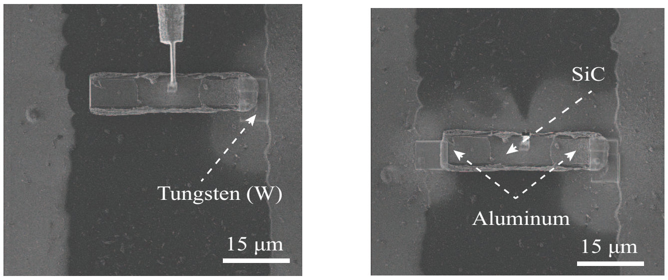


Figure 2: Scanning Electron Microscopy (SEM) images of cutting a p-3C-SiC resistor and transferring it onto SiO_2.

1.3 Releasing the SiC structures using dry a XeF_2 etching process

The XeF_2 etching was performed to release the SiC films from the Si substrate, using a pulse etching system[3]. This etching method is highly selective to Si, but not to aluminum and SiC. It also minimises adhesion between the SiC layer and the Si substrate owing to the dry gaseous characteristics of XeF_2. In the etching process follows the chemical reaction:

$$2XeF_2 + Si \rightarrow 2Xe + SiF_4 \tag{1}$$

2. Experimental setup for thermoresistive characterization

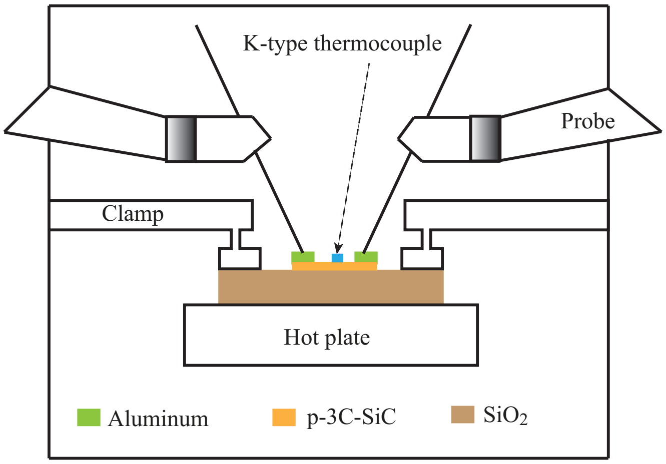


Figure 3: Experimental setup for characterization of SiC thermoresistance (not to scale).

Figure 3 shows the experimental setup for the thermoresistive characterization of the p-3C-SiC films[4]. The SiC platform was positioned on top of a hot plate (RT Stiring, Thermo Scientific), using two clamps. A K-type thermocouple (resolution 1 K, accuracy ±3%) was utilized for determining the temperature of the SiC strip. The electrical connections from the strip to a HP 4145B analyser were established with two probe tips pushed against the aluminum electrodes.

3. Current flow in the p-3C-SiC on Si substrate

It is important to investigate the current flow in the vertical and horizontal directions in the p-3C-SiC with the variation of temperature. Figure 4 shows the variation of the normalized currents with increasing temperature in both vertical and horizontal directions when a constant voltage of 1 V was applied. It is evident that at temperatures smaller than 350 K, a large band off-set (1.7 eV) between SiC and Si impedes the motion of carriers through the SiC/Si heterojunction. However, the current flowing in a vertical direction increases significantly with increasing temperature and contributes to approximately 50% of the input current at 450 K, while the horizontal current decreases by almost a half. This observation indicates that the SiC/Si platform is not a good choice for high-temperature MEMS thermal-based sensors. It also confirms a great need to transfer the SiC layer onto an insulation substrate.

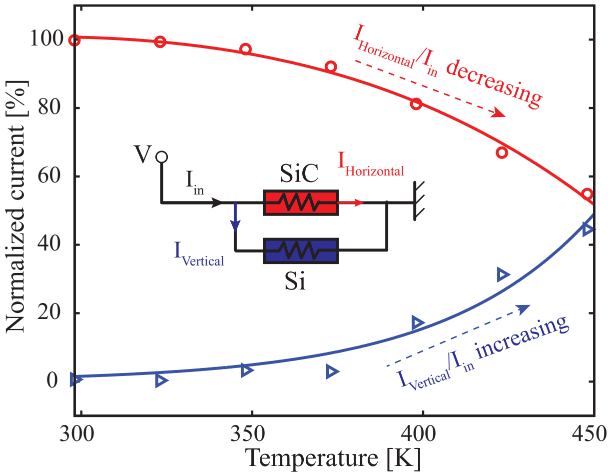


Figure 4: Current flow in the p-3C-SiC on Si substrate.

4. Thermoelectric effect of Al-W junctions

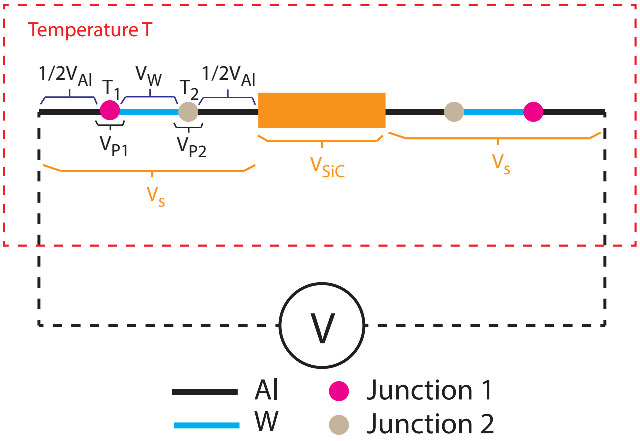


Figure 5: Junctions of the fabricated device.

The diagram of the junctions (Al-W) of the fabricated device is shown in Fig. 5. The Seebeck voltage V_s is the sum of two Peltier EMFs (V_{P1} and V_{P2}) and two Thomson EMFs (V_{Al} and V_W) given by^5:

$$Vs = (V_{P1} - V_{P2}) + (V_W - V_{Al}) \tag{2}$$

V_s is a measure of the difference in temperature ($T_1 - T_2$) of the two junctions. It is expected that the temperature distribution is theoretically uniform ($T_1 = T_2 = T$) when the device is heated on the hot plate. Therefore, $V_W - V_{Al} = 0$, ($V_{P1} - V_{P2}$)=0, and $V_s = 0$.

In addition, the measured voltage V can be calculated using:

$$V = 2V_s + V_{SiC} = 2V_s + I \times R \qquad (3)$$

where R is the resistance of the SiC and I is the applied current. The current-voltage characteristic shown in the manuscript (Fig. 3) indicates that there is no appearance of the thermoelectric voltage ($V_s = 0$), since $V = 0$ at $I = 0$.

Therefore, the impact of the thermoelectric effect of the Al-W junctions can be neglected.

References

[1] A. Qamar, H. P. Phan, D. V. Dao, P. Tanner, T. Dinh, L. Wang, and S. Dimitrijev, *Electron Device Letters*, 2015, **7**, 708.

[2] H. P. Phan, A. Qamar, D. V. Dao, T. Dinh, L. Wang, J. Han and N. T. Nguyen, *RSC Advances*, 2015, **5**(69), 073117.

[3] D. Xu, B. Xiong, G. Wu, Y. Wang, X. Sun, Y. Wang, *J. Microelectromechanical Systems*, 2012, **21**(6), 1436.

[4] T. Dinh, D. V. Dao, H. P. Phan, L. Wang, A. Qamar, N. T. Nguyen, P. Tanner and M. Rybachuk, *Applied Physics Express*, 2015, **8**(6), 061303.

[5] S. M. SZE, KWOK K. NG, *Physics of semiconductor devices*, 3rd ed, John Wiley and Sons, Inc., 2007, 748.