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Reliability of Pt ohmic contact on an undoped 3C-SiC micro-electrothermal device

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Abstract The objective of this paper is to investigate the reliability of platinum (Pt) ohmic metallization on an undoped 3C-SiC. The Pt layer is deposited on a SiC fabricated microcantilever using focused ion beam technique. The purpose of the Pt layers is to act as electrodes to generate electrothermal actuation from joule effect. The results showed an excellent ohmic contact formation. Over a period of storage at room temperature, deterioration of the ohmic contact had occurred. The effect of Schottky contact on the required power was also investigated by observing the decrease in the magnitude of the electrothermally vibrating device. An increase of resistance from 1 KΩ to few hundred KΩs was also reported.

1 Introduction

The Schottky barrier height (SBH) determines the electrical behaviour of an ohmic or Schottky contact (Davis and Porter 1995). An ohmic contact is characterized by linear voltage-current relation for both positive and negative voltages, as well as low resistance compared to the resistance of the bulk of the device. Therefore, an ohmic contact means low SBH. A rectifying contact has high SBH, and allows current to flow in one direction (Davis and Porter 1995).

Formation of the contact type depends on the application of use (e.g. rectifying contacts are widely used in fabricating microelectronic devices). SiC as a wide band gap semiconductor material is a promising material for high temperature and high frequency applications. A Schottky contact on SiC was successfully applied to fabricate diodes and mixer diodes (Neudeck and Simons 2003; Basu et al. 2003; Andersson et al. 2002). Formation of ohmic contact is a hard task compared with Schottky contact because most of Metals/semiconductors tend to form Schottky contact unless it is specially treated. Annealing is the process in which Schottky contact could be converted to ohmic contact. Generally, there are many factors which play a role in forming ohmic contact such as the doping nature of the semiconductor, and the characteristics of the metal and semiconductor used, as well as the working temperature (Andersson et al. 2002). A large number of metals could form Schottky or ohmic contacts on SiC (Davis and Porter 1995). With regard to the 3C-SiC, many metals were reported to form good ohmic contacts such as Ni, Al, Pt (Davis and Porter 1995). The work function of 3C-SiC was reported by Eriksson et al. (2010) to be around 4 eV compared to Pt which has a higher work function of 5.4 eV (Dey et al. 2006). At high temperatures, the possibility of metal/SiC reaction could cause degradation in the contact. For example, Ni contacts on n-type 3C-SiC annealed up to 600°C exhibit Schottky behaviour, and the same contact becomes ohmic when annealed at 900°C (Basu et al. 2003).

But when annealing at high temperature, an oxidation might occur which could form an oxide layer with the metal which could degrade the ohmic contact again. For this reason, another metal with high resistance to oxidation is deposited on top of the metal contact (Basu et al. 2003).

Although some of the materials were used to form ohmic contact with SiC, these contacts might degrade over time as a result of interaction with the environment. Cheng et al. (1997) reported an increase of contact resistance of Al/GaN over a period of 3 months storage at room temperature. Asamizu et al. (2003) also reported a deterioration of ohmic

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contact in Ti/GaN after a period of storage. Birkhahn et al. (2002) reported a significant increase in the resistance of an ohmic contact Au and Ni on P-GaN over a period of storage at laboratory. In the latter, the effect was suggested to be due to reaction with water vapour in the room. It should be mentioned here that, formation of ohmic contact is very necessary to apply voltages on semiconductor MEMS device. In this work Pt was deposited on SiC MEMS structure to act as an electrode to actuate the device using joule effect.

2 Fabrication

Micromechanical devices such as cantilevers are fabricated by microelectronics and micromechanical technologies.

A SiC cantilever was fabricated from undoped 3 μm thick single-crystal 3C-SiC film that was heteroepitaxially grown on a Si (100) wafer. SiO_2 was used as an etch mask layer which was deposited on the SiC film using plasma-enhanced chemical vapour deposition system. Photolithography was performed to pattern the oxide in the shape of the cantilever. A plasmatherm PK 2440 reactive ion etching system was used to remove the patterned SiO_2 layer exposing the SiC underneath. SiC was etched with inductively coupled plasma (ICP) using SF_6/O_2 gas mixtures. The width, length, and thickness of the cantilever are 15, 200, and 3 μm, respectively. Pt layer of 0.5 μm is deposited over the beam to form the electrodes using focused ion beam (FIB) technology (Brown et al. 2003). The design and the actual fabricated cantilever is shown in Fig. 1.

3 Electrothermal actuation

When an electric current is applied to the SiC layer, joule-heating effect causes thermal expansion of the beam. Applying a sinusoidal voltage results in a periodic change in temperature of the beam, this causes the beam to vibrate. The force is generated as a result of heat generated in the cantilever. The electrical energy is converted into heat energy across the SiC cantilever resistance. The resistance has a dc value of 1.2 KΩ. The heat energy Q is proportional to the rise in temperature ΔT above the ambient temperature:

$$Q = C_1.\Delta T \tag{1}$$

where the constant C_1 depends on the heated mass and the heat capacity.

Hence, the heat energy Q could be equated to $\frac{V^2.t}{R}$, where R is the beam's electrical resistance, V is the applied voltage, and t is heating time. The deflection of the cantilever tip, d, can be calculated using electromechanical model (Cabeca et al. 2002):

$$d = \frac{L^2}{t_{eq}} K.\Delta\alpha.\Delta T \tag{2}$$

where t_{eq} is the total equivalent thickness of the bilayer, K is a constant that depends on the ratio of young's modulus of the two layers of the cantilever, ΔT is the temperature rise above the starting temperature, and $\Delta\alpha$ is the difference in the thermal expansion coefficients of the two layers of the cantilever. Substituting ΔT of Eq. 2 into Eq. 1 and equating the resulting equation with $\frac{V^2.t}{R}$, yield the following expression;

$$d = \frac{V^2 L^2.K.\Delta\alpha.t}{C_1.t_{eq}.R} \tag{3}$$

From the above equation, the deflection is directly proportional to the square of voltage applied.

When applying an ac voltage which has a dc component, the square of the voltage would be;

$$V^2 = (V_{AC} \sin \omega t + V_{DC})^2$$
$$V^2 = 2V_{AC}V_{DC}. \sin \omega t + 0.5V_{AC}^2(1 - \cos 2.\omega t) + V_{DC}^2 \tag{4}$$

From the above equation; it is expected that when driving the beam with an ac signal at a frequency equals the resonance frequency of the beam, the dc bias would have a proportional effect on the amplitude of vibration "d". Whereas, when the driving voltage is at a frequency which is at half the resonance frequency. The effect of dc bias on the amplitude of vibration will be used to test the electrothermal actuation of the cantilever.

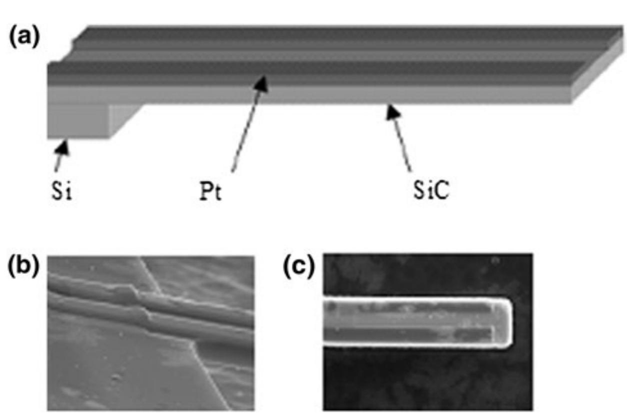

Fig. 1 The designed excited cantilever with the platinum contacts **a**, **b** and **c** are the SEM images of the fabricated device

4 Results and discussion

The resistance of the beam was measured to be 1.2 KΩ. This ohmic contact formed was necessary because the voltage drop across the contact should be significantly small compared with the drop across the active region. This resistance has changed over time of storage, of approximately 3 months, to a value of 200 KΩ at the time of taking the measurement, a value which is much higher than previously measured resistance. This indicates that the contact resistance between Pt and SiC has increased. This effect of the increase in ohmic resistance could be noticed by looking at the decrease in the amplitude of resonance as shown in Figs. 2 and 3.

The amplitude in the device was in the range of 3,000 nm using 0.3 V ac and 0.2 V dc. After the device deterioration, the amplitude was only 200 nm even though the ac was increased to 2 V and the dc was also increased to 1 V. This result is an indication that most of the voltage applied is dissipated at the contact resistance.

The device was also tested for the effect of dc at half resonance. In the earlier case (with good ohmic contact) the dc had no effect on the amplitude of resonance. Providing that there is a rectification occurring to the input signal as a result of the changes at the ohmic contact; the ac voltage at 2ω as in Eq. 4 will be rectified to a dc component and ac component; $(V_{AC}\sin 2\omega t + V_{DC})^2$, which would have dc and ac component at double resonance frequency as follow;

$$V^2 = 2V_{AC}V_{DC}.\sin 2\omega t + 0.5V_{AC}^2(1 - \cos 4.\omega t) + V_{DC}^2 \quad (5)$$

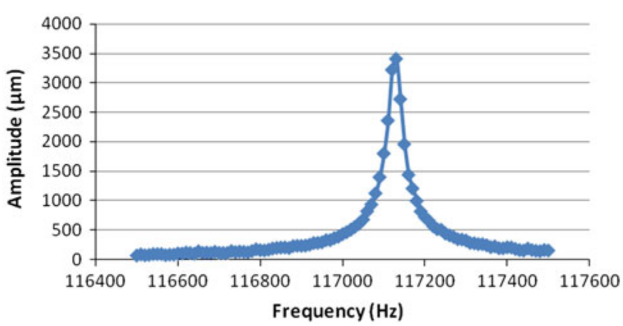

Fig. 2 The amplitude of resonance when applying 0.3 V ac and 0.2 V dc (before deterioration of the contact)

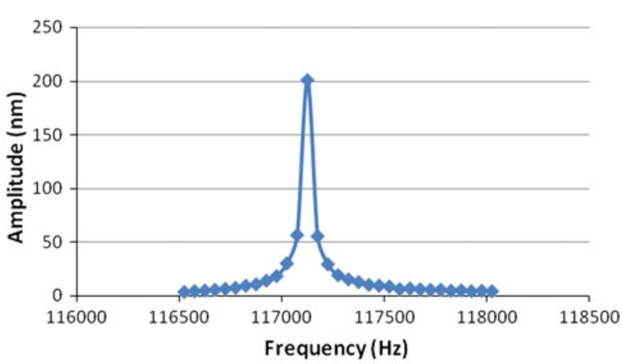

Fig. 3 The amplitude of resonance when applying 2 V ac and 1 V dc (after deterioration of the contact)

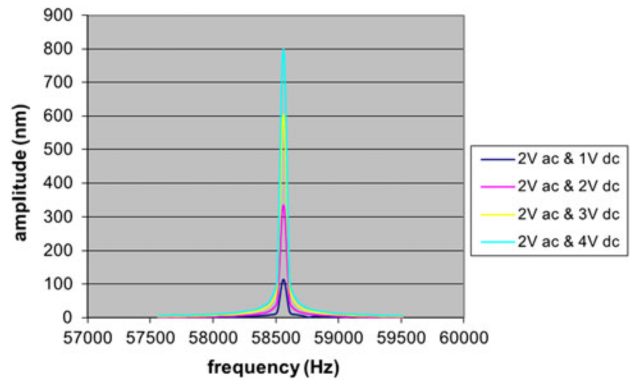

Fig. 4 The effect of dc bias at half resonance (58 kHz) as a result of rectifying contact

In this case, presence of rectification effect, it is expected that the dc bias would have an effect when the device is derived at half resonance as shown in Fig. 4.

The device was thermally heated by blowing hot air into the sample. This has caused the temperature of the device to increase. As a result, a significant decrease in the resistance was noticed. After thermally heating the device, the resistance has dropped to the original value again (1.2 kΩ). This value is similar to the measured resistance before deterioration of the Pt contact.

5 Conclusion

Deterioration of ohmic contact of pt/3C-SiC is reported. The deterioration has occurred over a period of 3 months storage time in room temperature. Pt is considered as a metal which could form good ohmic contact to undoped 3C-SiC provided that the device is properly stored in a vacuum. The degradation of the ohmic contact is possibly due to chemical interaction between the device and the environment. The mechanism of the interaction was not fully analysed. Thermally heating the device led to a change of the Schottky contact to an ohmic contact again. The device was electrothermally actuated successfully and the deterioration of the Pt/SiC ohmic contact required more electric power to drive the beam to the same amplitude. When heating the device for less than 3 min at temperature <100°C, the Schottky behaviour become ohmic again. These results suggest that, Pt metallization formed by FIB on an undoped 3C-SiC is not reliable for long term use unless heat treatment is applied.

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