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Development of Manganese Nitride Wiring with High Thermal Stability Caused by Saturation of the Mean Free Path

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Abstract

The resistance of the metal wirings increases with the temperature increase. This thermal instability requires redundancy of the circuits. It is well known that the anti-perovskite manganese nitride compounds show a broad resistance-temperature curve around room temperature. However, the broad resistance-temperature curves have been obtained with only the sintered bulk materials. In this study, we proposed manganese nitride wiring for high-thermal-stability systems. Then, we fabricated and evaluated the manganese nitride compound wiring with the CMOS-compatible process.

1. Introduction

CMOS ICs have been widely used in various applications, such as mobile phones, automobiles, medical devices. So, CMOS ICs are used under various temperature surroundings. On the other hand, heat generation due to circuit operations is one of the critical issues. Therefore, the thermal stability of CMOS ICs is one of the important characteristics, and high thermal stability is strongly required. The electrical characteristics of ICs will change by the carrier generation and increasing the carrier scattering induced by the heat. In this study, we focused on the saturation phenomena of the mean free path reduced by the carrier-scattering increase for high thermal stability.

2. Anti-perovskite Manganese Nitride

The electrical resistivity varies in inverse proportion to the mean free path which is the average distance an electron moves between two scattering events. In general, the mean free path is reduced by the temperature increase. Then, the mean free path is much larger than the separation of the atoms. However, a very limited number of materials shows invariant electrical resistivity with the changing temperature and near zero temperature coefficient of resistivity (NZ-TCR) behavior. In these materials, the mean free path reaches the separation of the atoms [1]. The materials which have NZ-TCR have been investigated in the state of bulk materials. It is known that anti-perovskite manganese nitride is one of them [2], [3]. Figure 1 shows the anti-perovskite crystal structure. It is considered that the mean free path is comparable to the interatomic separations in the anti-perovskite manganese nitride.

In this study, we tried to apply the manganese nitride material to the wirings used for resistance adjustment in CMOS ICs for realizing a high thermal stability system.

3. Fabrication

Conventionally, the manganese nitride compounds were investigated by only the sintered bulk materials. In this study, we formed the manganese nitride compounds layer with the typical sputtering system. Figure 2 shows the XRD spectrum of the manganese nitride compound target. We observed the intensity peak similar to the anti-perovskite manganese nitride made by the sintering method. We fabricated the manganese nitride compound wiring following the process flow shown in Fig. 3 (left). After the thermal oxidation process, we formed the wiring pattern by EB resist. In this study, we fabricated the wiring with the lift-off process. Thus, we formed the wiring pattern before the deposition of the wiring material. Then, the manganese nitride compound layer was deposited by RF magnetron sputtering. The sputtering pressure, power, and temperature are 0.5 Pa, 50 W, and room temperature. After that, we formed the manganese nitride compound wirings with the lift-off process. Finally, the samples were annealed at 400 °C. Figure 3 (right) shows the SEM image of the fabricated wiring. We could confirm the micro/nano-scale wiring made of the manganese nitride compound.

4. Results and Discussion

First, we measured the resistance of the Al wirings, which were fabricated for the comparison. The measurement results are shown in Fig. 4. The measurement temperatures were from 25 °C to 45 °C. The design value of the width of the measured wiring was 1.6 μm. We observed that the resistance increased with temperature increase. Figure 5 shows the resistance measurement results of the manganese nitride compound wiring. The design value of the width of the measured wiring was also 1.6 μm. We observed that there is little change in the resistance due to the temperature change. Figure 6 shows the effect of the temperature change on the resistance change ratio. The temperature coefficient of resistivity (TCR) of the Al wiring was 1162 ppm/°C. Then, the TCR of the manganese nitride compound wiring was approximately -80 ppm/°C less than 1/10 of the value of the Al wirings. It is considered that a small reduction of the resistance of the manganese nitride compound wiring is induced by the carrier generation around the Fermi level. These results indicated that the manganese nitride compound deposited by a typical sputtering system could also show NZ-TCR behavior.

5. Conclusion

We demonstrated that micro/nano-scale wirings of the manganese nitride compound showed the broad resistance-temperature curves around the room temperature for the first time. The measurement results indicate that the manganese nitride compounds have the possibility to achieve higher thermal stability compared to conventional wirings, such as poly-silicon resistance.

Acknowledgements

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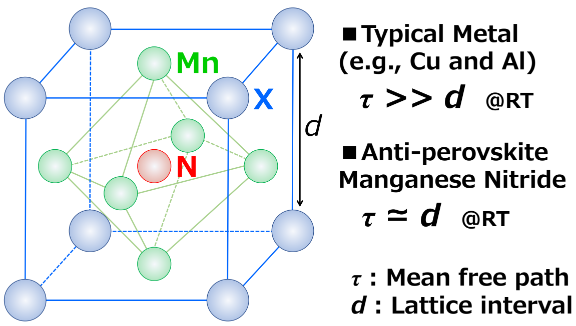

Fig. 1 Anti-perovskite crystal structure of manganese nitride compounds.

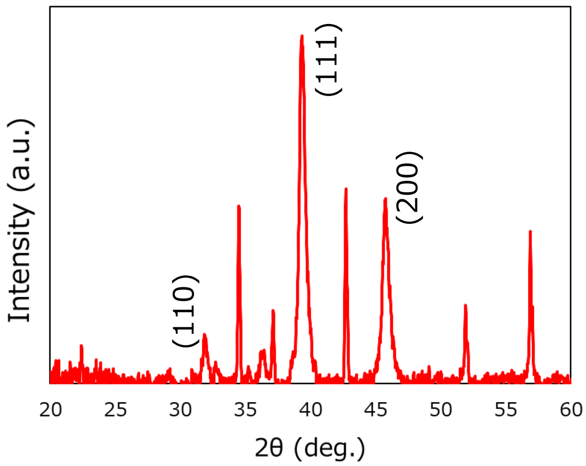

Fig. 2 XRD spectrum of the manganese nitride compound sputtering target.

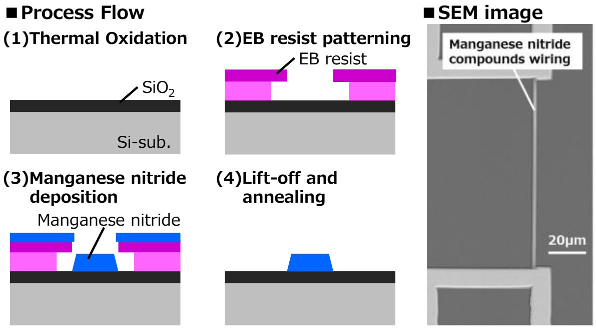

Fig. 3 Process flow (left) and SEM image (right) of the manganese nitride compound wiring.

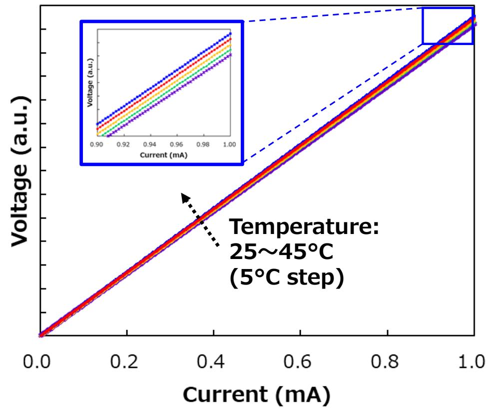

Fig. 4 *I-V* characteristics of the Al wiring under the temperature change.

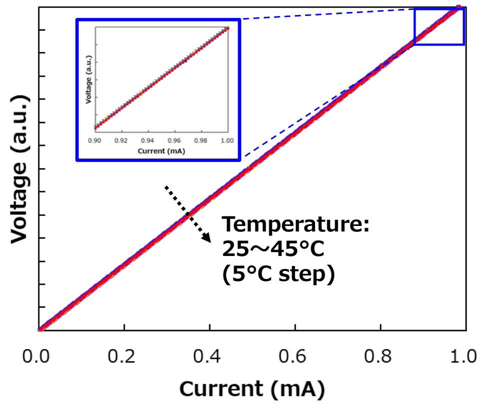

Fig. 5 *I-V* characteristics of the manganese nitride compound wiring under the temperature change.

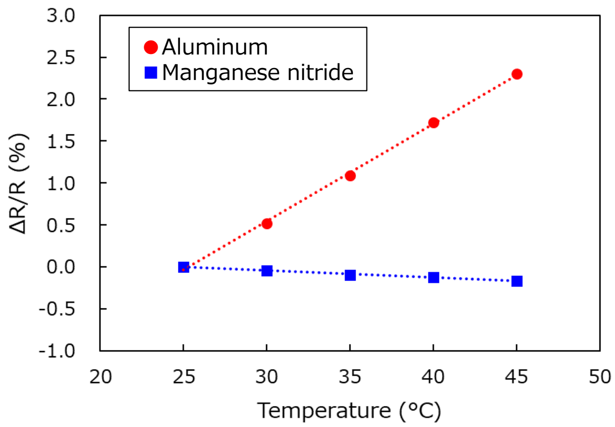

Fig. 6 Temperature dependence of the resistance change ratio of the manganese nitride compound wiring and the Al wiring.