Fabrication of Bulk-type Silicon Thermoelectric Material Using Silicon Nanowire

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Introduction

Thermoelectric materials can generate electricity from waste heat and play an important role in sustainable energy field, but the practical application of thermoelectric devices is mainly limited by the material cost and insufficient ZT.[1)] One of the restrictions for large area fabrication and the reduction of fabrication cost is that thermoelectric contained Si substrate. In this study, we explored using silicon nanowires (SiNWs) without Si substrate as raw materials to fabricate bulk-type silicon thermoelectric material. The purpose of the study is to realize bulk-type silicon thermoelectric material with lower cost and sufficient ZT.

Methodology

The SiNWs were prepared by metal-assisted chemical etching (MACE) at room temperature. The n-silicon (≤0.001 Ω*cm) with a (100) crystal orientation was used for the preparation of SiNWs. First, the Si substrate was immersed into a solution of 4.8 M HF and 0.015 M $AgNO_3$ for 10 s for electroless silver plating (ESP) to form silver particles, after that the samples were immersed in the 4.8 M HF solution and 0.1 M H_2O_2 for 4 h to MACE. Then the bulk-type silicon thermoelectric material was fabricated by spark plasma sintering (SPS). The pressure of SPS was set as 8.8 KN, and 0.5 g SiNWs were stringed respectively under the temperature 900, 1000, 1150, and 1250 ℃ for 1 min.

Results and discussion

The results show that when temperature was 900 ℃ and 1250℃, the thermoelectric samples were cracked due to the inability of grains bonding at too low or high temperatures. In addition, although the thermoelectric sample can be formed when temperature was 1000 ℃, the sample was not conductive, which indicated that the grains of thermoelectric sample were not bonded tightly enough. When the temperature was 1150 ℃, the thermoelectric sample can be formed. The diameter of the sample was 1.5 cm with a thickness of 1.3 mm, and the density was 1.9 g/cm^3. The thermal conductivity of the sample was 14 $W{\cdot}m^{-1}{\cdot}K^{-1}$, and the thermoelectric of the sample ZT was 0.015. As the thermal conductivity of crystalline silicon is 140 $W{\cdot}m^{-1}{\cdot}K^{-1}$, the value of 14 $W{\cdot}m^{-1}{\cdot}K^{-1}$ indicated that SiNWs with high porosity can significantly reduce the thermal conductivity of bulk-type silicon thermoelectric material. On the other hand, and the further improvement of ZT value of 0.015 is expected through controlling the amount of Ag in the MACE process. The advantage of this method is that fabrication of bulk-type silicon thermoelectric material in large size can be possible because there were no composite structures.

References

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