Direct Electrodeposition of Bi$_2$Te$_3$ Thin Films on Porous Silicon

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Bi$_2$Te$_3$ thin films have attracted increasing interests in recent years due to its superior ZT near room temperature. Various techniques have been applied to synthesize Bi$_2$Te$_3$ films such as chemical vapor deposition, molecular beam epitaxy and electrodeposition. Compared to other methods, electrodeposition is one the most cost-effective techniques for the fabrication of Bi$_2$Te$_3$ thin films because of the advantages of room temperature operation, low equipment cost and high deposition rate. Bi$_2$Te$_3$ thin films are usually electrodeposited on metal substrates due to their good electrical conductivity and well-defined interfaces. Several metal substrates not attacked by the acidic electrolyte have been studied: stainless steel, Au and Pt. There is lack of research of direct electrodeposition of Bi$_2$Te$_3$ thin films on silicon which is attributed to the lower conductivity of silicon compared to metal and the poor adhesion between the Bi$_2$Te$_3$ thin films with silicon substrate.

Here we report that Bi$_2$Te$_3$ thin films can be directly electrodeposited on porous silicon from an electrolyte containing Bi (NO$_3$)$_3$ and TeO$_2$ in acidic conditions, which shows the potential for the integration of nanostructures with Si-based microelectronics. Physical analysis by X-ray diffraction (XRD), scanning electron microscope (SEM) and energy dispersive spectroscopy (EDS) confirm that the deposits are Bi$_2$Te$_3$ thin films which exhibit a preferential orientation along the (110) direction. The nucleation process of the film is investigated by changing how electrode is contacted with samples and the result shows that pores help the first nucleation of Bi$_2$Te$_3$ on the porous silicon.

XRD patterns of deposits obtained at different applied potentials are shown in Figure 1. Thin films deposited at -400 mV showed good crystallinity and the highest (110) peak. The typical EDS result is presented in Table 1 which showed that the stoichiometry of the potentiostatically deposited film was dependent on the applied potentials. When -400 mV was applied, the deposited Te content in Bi$_2$Te$_3$ films was 61.8%, which proved that the deposited film was Bi$_2$Te$_3$.

SEM images in Figure 2 clearly show that Bi$_2$Te$_3$ thin films could be directly deposited on porous silicon. The morphologies of electrodeposited films were strongly affected by the film compositions and deposition potentials. The Te-rich Bi$_2$Te$_3$ thin films consisted with needle-like structure, which corresponded to the reports of other research groups. Additionally, we investigated the effect of the position of electrode contact on the nucleation process. Pores were covered with Bi$_2$Te$_3$ when the electrode was contact with porous silicon, while there were many Bi$_2$Te$_3$ nanorods on the surface of porous silicon when some parts of porous silicon were etched and made the electrode contact with silicon (Figure 3).

Applied Potential | Bi content | Te content | Bi$_2$Te$_3$
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<tbody>
<tr>
<td>-300mV</td>
<td>15.0%</td>
<td>85.0%</td>
<td>Bi$<em>{1.6}$Te$</em>{1.2}$</td>
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<tr>
<td>-400mV</td>
<td>38.2%</td>
<td>61.8%</td>
<td>Bi$<em>{1.9}$Te$</em>{1.1}$</td>
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<tr>
<td>-500mV</td>
<td>32.7%</td>
<td>67.3%</td>
<td>Bi$<em>{1.4}$Te$</em>{1.4}$</td>
</tr>
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Table 1. Composition of Bi and Te in samples with different applied potentials.

References