

# Systematic Study on Synthesis of High Quality SnTe Layers by Molecular Beam Epitaxy

**Qihua Zhang**<sup>1,a)</sup> **Maria Hilse**<sup>1,2</sup> **Jennifer Gray**<sup>3</sup> **Max Stanley**<sup>4</sup> **Nitin Samarth**<sup>1,2,4</sup> and **Stephanie Law**<sup>1,2,a)</sup>

<sup>1</sup>*Two-dimensional Crystal Consortium - Materials Innovation Platform, Materials Research Institute, The Pennsylvania State University, University Park, Pennsylvania 16802, USA*

<sup>2</sup>*Department of Materials Science and Engineering, The Pennsylvania State University, University Park, Pennsylvania 16802, USA*

<sup>3</sup>*Materials Characterization Lab, Materials Research Institute, The Pennsylvania State University, University Park, Pennsylvania 16802, USA*

<sup>4</sup>*Department of Physics, The Pennsylvania State University, University Park, Pennsylvania 16802, USA*

Tin telluride (SnTe) is a narrow bandgap semiconductor which has many attractive properties, such as in-plane ferroelectricity, good thermoelectric performance, and a topological crystalline insulator (TCI) band structure.<sup>1</sup> In addition to these properties, SnTe also serves as an important buffer layer for developing Te-based heterostructures for magneto-transport devices.<sup>2</sup> Despite such promises, there have been few investigations focused on understanding the optimal epitaxial growth conditions for SnTe layers, which has led to poor surface morphologies and/or low crystallinity in synthesized films.<sup>3</sup> A major challenge in the growth of thin film SnTe is the lack of suitable substrates, owing to the rock-salt crystal structure of SnTe and the large lattice mismatch with common substrates.

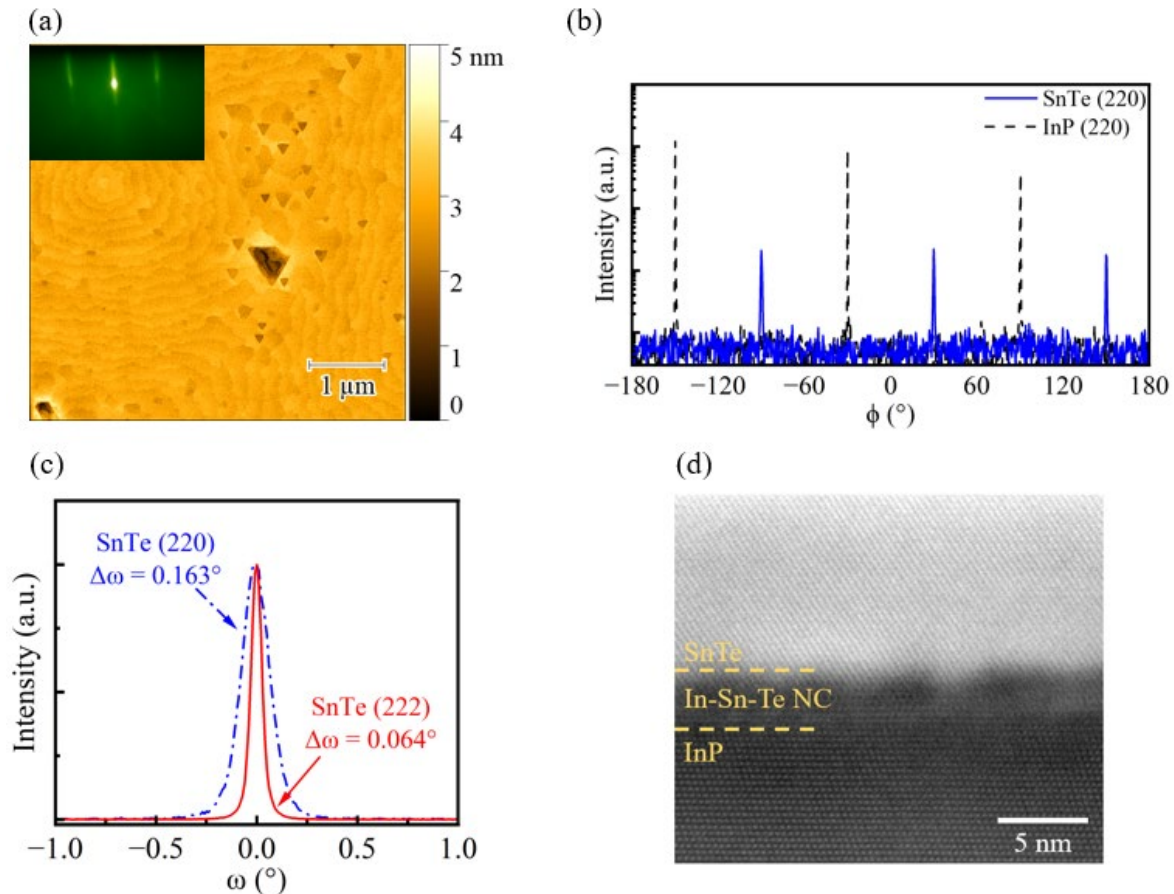
In this study, we report on the molecular beam epitaxy (MBE) growths of SnTe(111) layers on InP(111)A substrates. We have conducted a detailed investigation of the surface morphology and film crystal quality based on growth parameters including substrate temperature, Te/Sn flux ratio, and film growth rate. Despite the 7.4% lattice mismatch between the film and substrate, we found that a narrow substrate temperature range from 300 °C to 340 °C, a Te/Sn flux ratio of ~3, and a growth rate of 0.48 Å/s yield both smooth and single-crystalline SnTe(111) layers with thicknesses ranging from 10 nm up to 800 nm. Using these conditions, fully coalesced and smooth SnTe layers with root-mean-square (rms) roughness as low as 0.3 nm (Fig. 1a) can be obtained. The as-grown SnTe layer is free of rotational twin domains (Fig. 1b) and has exceptional crystal quality, including a full-width-at-half-maximum (FWHM) value as narrow as 0.06° from x-ray diffraction (XRD) rocking curves (Fig. 1c). Reciprocal space mapping confirms that thin (15 nm) SnTe layers are fully relaxed. Detailed transmission electron microscopy (TEM) imaging suggests that formations of In-Sn-Te nanoclusters during substrate annealing in a Te environment prior to growth aids strain relaxation as well as improves crystalline quality (Fig. 1d). Finally, preliminary angle-resolved photoelectron spectroscopy further indicates the three-fold symmetry of SnTe (111) layer at the  $\Gamma$  point, as well as Fermi level located 0.19 eV below the Dirac point. These promising results lay the foundation for employing SnTe on InP as a platform for developing all-telluride heterostructures integrated with III-V semiconductor devices.

[1] DOI:10.1063/5.0012300.

[2] DOI:10.1038/ncomms11623.

[3] DOI:10.1002/pssa.202200555.

a) Authors for correspondence: [qzz5173@psu.edu](mailto:qzz5173@psu.edu) and [slaw@psu.edu](mailto:slaw@psu.edu)



**Figure 1.** (a) AFM image of SnTe surface with a  $5 \times 5 \mu\text{m}^2$  scan area. Inset shows the RHEED taken immediately after the growth of SnTe layer. (b) XRD  $\phi$ -scans of SnTe (220) (blue solid line) and InP (220) (black dashed line) diffractions, denoting the lack of rotational domains in the SnTe layer. (c) XRD rocking curves of SnTe (222) (red solid line) and (220) (blue dashed line) diffraction peaks. The FWHM from each rocking curve is labeled. (d) HAADF-STEM image of SnTe/InP interface. Nanoclusters (NC) consisting of In, Sn, Te are observed between the SnTe and InP interface.