

## Crystallographic Relationships in the Synthesis of Nanoscale Metal Telluride Phases

K. L. Thompson, R. R. Katzbaer, P. L. Herring, M. Terrones, R. E. Schaak

Nanoscale metal telluride materials are often challenging to synthesize colloiddally due to the propensity to form elemental tellurium or tellurium oxide and the need for reactive precursors to promote metal telluride formation. Interestingly, utilizing crystallographic relationships and diffusion-based processes can effectively yield nanoscale metal telluride products. Anion exchange is a diffusion-based process in which one anion is removed and replaced by another. In an anion exchange process, aspects of the original particle, such as morphology and crystalline features, are typically retained. By choosing two materials that adopt the same crystalline phase, weissite  $\text{Cu}_{2-x}\text{Se}$  and  $\text{Cu}_{2-x}\text{Te}$ , we demonstrated the first example of complete structural retention after tellurium anion exchange. Interestingly, the exchange yielded an anion solid solution that was tunable pending the amount of tellurium precursor used. Additionally, the solid solution composition changed over time due to a subsequent outward diffusion of tellurium. As another metal telluride example, niobium tetratelluride ( $\text{NbTe}_4$ ) is a phase typically formed through high-temperature solid state techniques by reacting elemental niobium and tellurium. We developed a solution method to form  $\text{NbTe}_4$  through a diffusion process in which Nb first deposits on the surface of a hollow Te needle and then a simultaneous inward diffusion of Nb and outward diffusion of Te forms the  $\text{NbTe}_4$  particles. This phase formation is dictated by the crystallographic relationships between  $\text{NbTe}_4$  and elemental tellurium. Both structures contain one-dimensional tellurium chains ( $\text{NbTe}_4$  has zigzags and Te has spirals) that only require minor localized rearrangements to transform one into the other. Thus, this work demonstrates the importance of crystallographic relationships when targeting nanoscale metal telluride systems and highlights that diffusion-based methods can expand the phase space of colloiddally synthesized materials.