Tunable electrical conductivity in ferromagnetic semiconductor samarium nitride

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Rare-earth nitrides (RENs) are an exciting family of materials with a wide variety of properties desirable in the field of spintronics, infrared detectors, intrinsically ferromagnetic-based tunnel junctions, and as strongly correlated electron materials. The electronic configuration of elements containing 4*f* orbitals is a source of interesting new physics: as an example, samarium nitride (SmN) has been reported to support the coexistence of semiconductor behavior, ferromagnetic states, and superconductivity. Motivated by these properties and exciting opportunities, there has been an increased interest in the synthesis and study of high-quality rare-earth nitride materials. In this study we present an analysis of the synthesis of SmN thin films on MgO(001) using molecular beam epitaxy with varying growth conditions to create different levels of N vacancies. We report on the structure of different samples grown under different regimes of N availability and substrate temperature (T_{sub}), and measure their transport properties as a function of carrier concentration. We find that T_{sub} impacts the availability of carriers by a factor of 13x, compared to N availability that only increases carriers by a factor of 2x.

Structural characterization of these films indicate a uniform rocksalt crystal structure, with no appreciable difference in lattice constant or crystal quality beyond the difference in full width half-maximum of the SmN(200) peak of >0.14º. These promising results indicate a path forward in the epitaxy of versatile materials able to provide monolithic integration of different electronic behaviors without the associated strain brought about by heteroepitaxial integration of dissimilar materials.

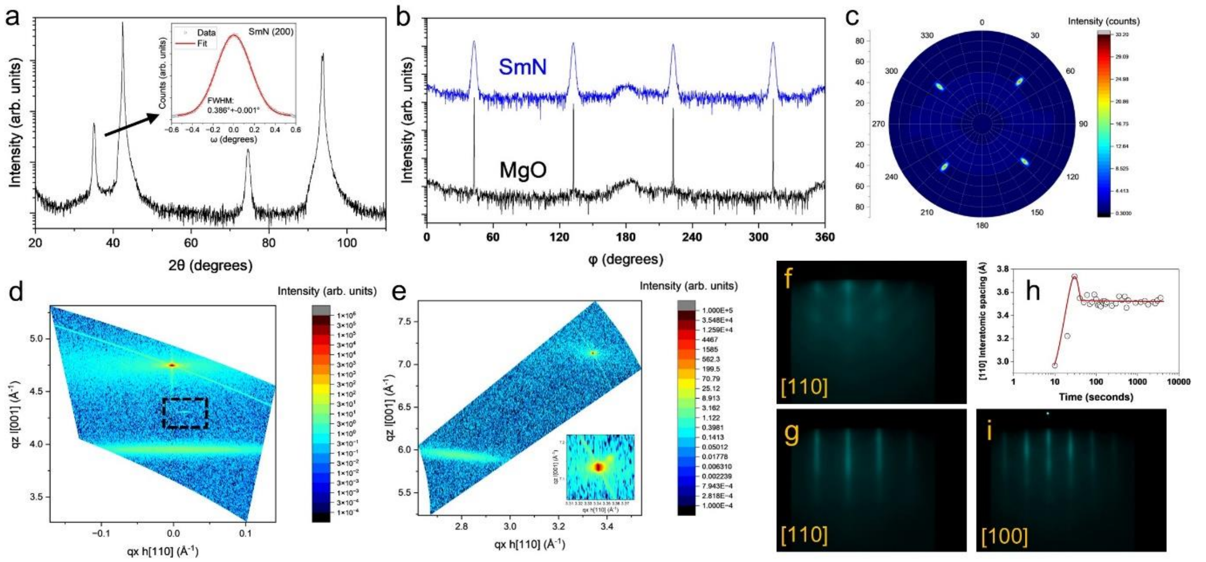

Figure 1: Diffraction characterization of SmN samples grown on MgO(001). (a) X-ray diffraction pattern displaying only SmN and MgO (00n) (n being even) planes. (b) Phi scan showing the registry of SmN(200) to MgO(200), further confirmed by the pole figure in (c). Symmetric and asymmetric reciprocal space maps show the presence of a Sm-O peak (highlighted area in (d)) and the CrN cap in the inset in (e). (f)-(i) show the RHEED pattern evolution for the sample during growth. A high-quality surface is present at the end of 60 minutes of growth, with the previously reported Sm-O layer indicated by the expansion of the lattice constant during the first two nanometers of growth.

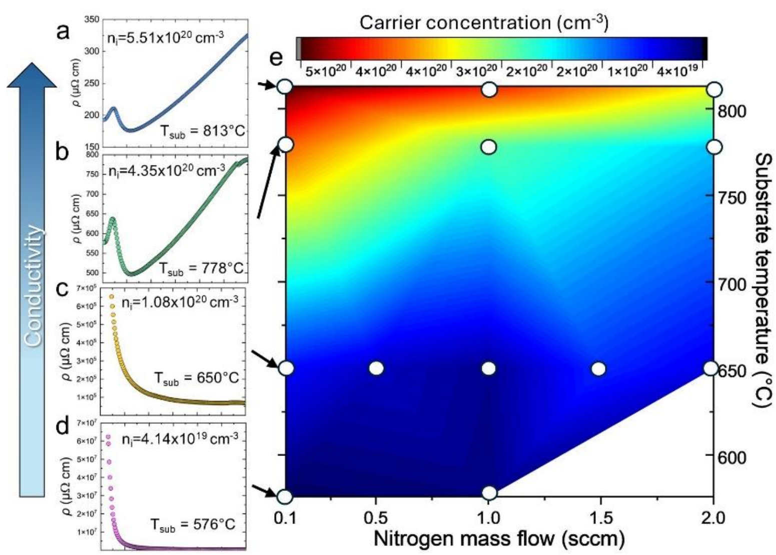

Figure 2: Parameter space for carrier concentration as a function of N mass flow and T_{sub} for growth of SmN on MgO. At a constant growth rate, it is evident that higher Tsub and lower N mass flow produce the largest number of available carriers due to the low incorporation of N to the sample. (a)-(d) show the resistivity as a function of temperature and a clear transition from insulating to conducting is present as a function of carrier availability. A feature attributed to the onset of ferromagnetism is present in all conductive samples at ~ 27 K.