Metal/Semiconductor Superlattice Metamaterials: A New Paradigm in Solid-State Energy Conversion

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Since the 1960s, researchers exploring the potential of artificially-structured materials for applications in quantum electronic devices have sought combinations of metals and semiconductors that could be combined on the nano-scale with atomically-sharp interfaces. Early work with multilayers of polycrystalline elemental metals and amorphous semiconductors showed promise in tunneling devices. More recently, similar metal/semiconductor multilayers have been utilized to demonstrate novel optical metamaterials. These metal/semiconductor multilayers, however, are not amenable to atomic-scale control of interfaces. We developed the first epitaxial metal/semiconductor multilayer and superlattice heterostructures that are free of extended defects. These rocksalt nitride superlattices have atomically sharp interfaces and properties that are tunable by alloying, doping and quantum size effects. Furthermore, these nitride superlattices exhibit exceptional mechanical hardness, chemical stability and thermal stability up to ~1000℃.

In this presentation, I will describe the growth, structural characterization and transport properties of nitride metal/semiconductor superlattices including (Ti,W)N/(Al,Sc)N and (Hf, Zr)N/ScN. ScN and $Al_xSc_{1-x}N$ ($x < 0.82$) are rocksalt semiconductors in thin film and bulk form that can be doped preferentially with *n*-type or *p*-type carriers. $Al_xSc_{1-x}N$ can also be stabilized in rocksalt phase for high AlN mole fractions by lattice-matched epitaxy. TiN, ZrN, HfN and similar transition metal nitride films can be good metals with carrier concentrations approaching 10^{22} cm^{-3}. Potential applications of these single crystalline superlattice and thin films in thermoelectric devices and plasmonic metamaterials will be discussed. Furthermore, recent experimental efforts to employ these superlattices as model materials for investigating the fundamentals of heat transport in nanostructured materials will be addressed.

Reference:

1. B. Saha, A. Shakouri and T. D. Sands, "Rocksalt Nitride Metal/Semiconductor Superlattices: A New Class of Artificially-Structured Materials". *Appl. Phys. Rev. 5, 021101 (2018).*