

Tailoring of surface plasmon resonances in TiN/(Al,Sc)N superlattices for applications in energy-harvesting devices

Garbrecht, M.¹ and Saha, B.²

¹ Thin Film Physics Division, Linköping University, Sweden, ² International Center for Materials Science & Chemistry and Physics of Materials Unit, Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), India

Alternative designs of plasmonic metamaterials for applications in solar energy-harvesting devices are necessary due to the high losses that pure noble metal-based nanostructures suffer from in the visible spectrum. In the present study we demonstrate the design of a material based on a superlattice architecture with systematically varying dielectric interlayer thicknesses that result in a continuous shift of surface plasmon energies. Plasmon resonance characteristics of metal/semiconductor TiN/(Al,Sc)N superlattice thin films were analyzed using aberration-corrected and monochromated STEM-EELS [1].

Surface plasmons of metallic nanostructures localize light below the diffraction limit and can generate intense electric near-fields with well-defined resonances within the optical window [2]. Applications include single-molecule spectroscopy, molecular sensors, photothermal cancer therapy, photocatalytics, and photovoltaics [3]. Plasmonic nanostructures comprise hitherto mostly noble metals like gold and silver, which are not compatible with standard CMOS technology for continuous film growth due to their limited chemical and thermal stability. As an alternative, the extraordinarily temperature stable and chemically inert transition metal nitrides have been found to exhibit plasmonic properties similar to gold [4-6].

Transition metal nitrides such as TiN can be grown as a constituent of single-crystal thin-film epitaxial metal/semiconductor superlattices with low defect densities, exhibiting high melting points and mechanical hardness [5-12]. In addition to its high chemical and thermal stability, a TiN/(Al,Sc)N superlattice architecture with metal/dielectric interfaces has been proven a promising hyperbolic metamaterial in the visible spectral range and demonstrated large enhancement of its densities of photon states which could be useful in various quantum electronic and optoelectronic applications [13]

We have investigated the influence of semiconductor interlayer thicknesses on the bulk and surface plasmons of TiN in thin film superlattices with systematically increasing (Al,Sc)N interlayer thicknesses [14]. While the TiN bulk plasmon keeps a constant value of about 2.50 eV, the surface resonance continuously decreases with increasing interlayer thickness until converging at about 2.16 eV once the interlayer reaches a thickness comparable to the one of TiN (Fig. 1).

This effect can be understood to be the result of resonant coupling between the TiN bulk- and surface plasmons across the dielectric interlayers at very low (Al,Sc)N thicknesses. The detected plasmon resonance energies correspond to wavelengths between 500-600 nm, i.e. in the visible light range of the electromagnetic spectrum. Our results show that by carefully controlling the (Al,Sc)N interlayer thickness in the superlattice stack, TiN surface plasmon energies can be tailored, potentially enhancing the efficiency of solar energy-harvesting devices.

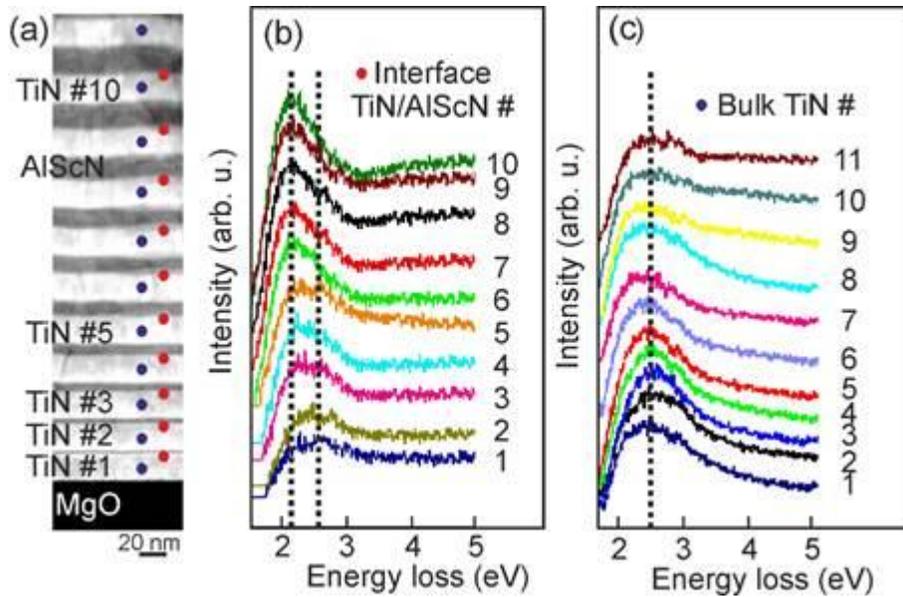


Fig. 1. EELS spectra taken from the positions marked in the STEM overview (a): Surface (b), and bulk (c) TiN inelastic scattering profiles after background subtraction showing a systematic reduction in surface plasmon resonance energy with increasing (Al,Sc)N interlayer thickness (b), while the TiN bulk plasmon resonances show no systematic changes (c).

- [1] The KAW Foundation is acknowledged for Linköping's EM Laboratory.
- [2] M. I. Stockman, *Opt. Express* 19, 22029 (2011).
- [3] S. A. Maier, *Plasmonics: Fundamentals and Applications* (Springer Science & Business Media, 2007).
- [4] G. V. Naik et al., *Opt. Mater. Express* 2, 478 (2012).
- [5] A. A. Herzing et al., *Appl. Phys. Lett.* 108, 171107 (2016).
- [6] B. Saha et al., *Appl. Phys. Lett.*, 105:151904, (2014).
- [7] J. L. Schroeder et al., *J. of Mater. Sci.* 50: 3200-3206, (2015).
- [8] B. Saha et al., *Phys. Rev. B.*, 93, 045311, (2016).
- [9] M. Garbrecht et al., *J. Mater. Sci.* 51(17), 8250 (2016).
- [10] M. Garbrecht et al., *Phys. Rev. Materials* 01, 033402 (2017).
- [11] B. Saha et al., *Appl. Phys. Lett.* 110, 252104 (2017).
- [12] M. Garbrecht et al., *Sci. Rep.* 7, 46092 (2017).
- [13] B. Saha et al., *Sands, Phys. Rev. B* 90, 125420 (2014).
- [14] M. Garbrecht et al., *J. Mater. Sci.* 53(6) 4001-4009. (2018).