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Semiconductor Hyperbolic Metamaterials at the Quantum Limit

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Hyperbolic metamaterials (HMs) [1] are a special class of metamaterials made of metallodielectric multilayers that play a key role in the field of nanophotonics because of the extreme anisotropy that can be created artificially. Recently, it has been discovered that because highly-doped semiconductors can behave like metals at certain frequencies, a new class of hyperbolic metamaterials (called semiconductor hyperbolic metamaterials, SHMs) can be fabricated by using epitaxial growth of alternating layers of sub-wavelength undoped (barriers) and highly-doped (well) layers of semiconductor material [2]. SHMs offer unprecedented control of carrier concentration, layer thicknesses, and interface smoothness when compared to conventional metal/dielectric counterparts, and also feature higher carrier mobilities.

In this work, we study SHMs at the quantum limit experimentally using spectroscopic ellipsometry [3] as well as theoretically using a new microscopic theory [4]. The theory is a combination of microscopic density matrix approach for the material response and Green's function approach for the propagating electric field. Our approach predicts absorptivity of the full multilayer system and for the first time allows the prediction of in-plane and out-of-plane dielectric functions for every individual layer constructing the SHM as well as effective dielectric functions that can be used to describe a homogenized SHM.

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