From surface to volume plasmons in hyperbolic metamaterials: General existence conditions for bulk high-k waves in metal-dielectric and graphene-dielectric multilayers.

We theoretically investigate general existence conditions for broadband bulk large-wave-vector (high-k) propagating waves (such as volume plasmon polaritons in hyperbolic metamaterials) in subwavelength periodic multilayer structures. Describing the elementary excitation in the unit cell of the structure by a generalized resonance pole of a reflection coefficient and using Bloch’s theorem, we derive analytical expressions for the band of large-wave-vector propagating solutions. We apply our formalism to determine the high-k band existence in two important cases: the well-known metal-dielectric and recently introduced graphene-dielectric stacks. We confirm that short-range surface plasmons in thin metal layers can give rise to hyperbolic metamaterial properties and demonstrate that long-range surface plasmons cannot. We also show that graphene-dielectric multilayers tend to support high-k waves and explore the range of parameters for which this is possible, confirming the prospects of using graphene for materials with hyperbolic dispersion. The approach is applicable to a large variety of structures, such as continuous or structured microwave, terahertz, and optical metamaterials.

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