Magneto-Induced ac Electrical Permittivity of Metal-Dielectric Composites with a Two Characteristic Length Scales Periodic Microstructure

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A new effect was recently predicted in conducting composites that have a periodic microstructure: an induced strongly anisotropic dc magneto-resistance [1]. This phenomenon is already verified on high mobility n-GaAs films [2]. Here we discuss the possibility of observing analogous behavior in the ac electric permittivity of a metal-dielectric composite with a periodic microstructure in the presence of a strong magnetic field. We developed new analytical and numerical methods to treat the low-frequency magneto-optical properties in composite media with both disordered and periodic conducting micro-structures. Those methods allow us to study composites with inclusions of arbitrary shape (and arbitrary volume fraction) at arbitrarily strong magnetic field. This is exploited in order to calculate an effective dielectric tensor for this system as a function of applied magnetic field and frequency. We show that in a non-dilute metal-dielectric composite medium the magneto-plasma resonance and the cyclotron resonance depend upon both the applied magnetic field as well as on the geometric shape of the inclusion. Near such a resonance, it is possible to achieve large values for the ratio of the off-diagonal-to-diagonal electric permittivity tensor components, $\varepsilon_{xy}/\varepsilon_{zz}$, (since $\varepsilon_{zz} \to 0$, while $\varepsilon_{xy} \neq 0$), which is analogous to similar ratio of the resistivity tensor components, $\rho_{xy}/\rho_{xx}$, in the case of dc magneto-transport problem. Motivated by this observation and by results of previous studies of dc magneto-transport in composite conductors, we then performed a numerical study of the ac magneto-electric properties of a particular metal-dielectric composite film with a periodic columnar microstructure which has a two characteristic length scales. The unit cell of such composite is prepared as follows: We placed the conducting square (in cross section) rods (first characteristic length scale) along the perimeter of the unit cell in order to create a dielectric host with large $\rho_{xy}/\rho_{xx}$ ratio. Then the insulating island in the center of the unit cell serves as an effective obstacle (second characteristic length scale). When the frequency is in the vicinity of one of the sharp resonances, there appears a strong dependence of the real and imaginary parts of all the components of the bulk effective electric permittivity tensor, $\varepsilon^{(e)}$, on both the magnitude and the direction of the applied static magnetic field, $B$, which is rotated in the film-plane [3]. The various magneto-optical properties (including Faraday rotation, etc.) of such composites are considered. The possibility of observing these new effects in a suitably synthesized composite film is considered in detail.