Fabrication of a composite consisting of a metal matrix with isolated dielectric inclusions by thin film deposition techniques used in this and other studies [22,23] might be complex, since the island growth is characteristic for metals and not dielectrics. Alternatively, there are several techniques for fabrication of metal films with isolated dielectric inclusions, specially voids: nanoporous gold from cluster beam deposition [48], disorder nanohole arrays from colloidal lithography [49] or nanoscale casting with electrochemical deposition [50]. Indeed, the effective dielectric function of nanoporous gold determined in reference [48] show absence of localized surface plasmon resonance in the visible range, as suggested from the above theoretical analysis.

5. Conclusions

It has been shown that a metal-dielectric composite with effective dielectric function described in the framework of classical effective medium theories can provide a negative dielectric function with small imaginary part based on the surface plasmon resonance of isolated inclusions (Maxwell-Garnett) or on the percolation of metal inclusions (Bruggeman). This observation appears from the analysis of the classical effective medium theories in the context of the spectral density representation, that explicitly states the influence of the composite geometrical configuration through the topological resonances of the system. Although both theories can lead to a negative real part of the effective dielectric function and small absorption, the Bruggeman composite presents an extended degree of wavelength tuning and improved performance.

The determination of the effective dielectric function of fabricated random metal-dielectric composites using optical spectroscopy indicates that real random systems have higher absorption than predicted by effective medium theories. These discrepancies, that limit the composite potential for metamaterial applications, appear to be closely related to the random nature of the mixtures. Thus, in systems consisting of isolated metal particles in dielectric matrix, the local field fluctuations lead to a wide range of topological resonances instead of the single resonance considered in the Maxwell-Garnett theory. This results in a surface plasmon resonance broader than the predicted by the theory, reducing the range of negative values that the real part of the effective dielectric function can take and increasing its imaginary part. The composites for which tuning of the effective dielectric function is based on percolation of the metal component, have spectral density functions consisting of a continuous distribution of all possible topological resonances, typical for fractal structures. As a result, such composites present higher absorption for the wavelength range where tuning is desired, when compared to the Bruggeman theory.

These results indicate that mixtures with the metal component being percolated, but not having a fractal nature, should present higher quality factors for metamaterial applications than the composites fabricated in this study. This is the case of a metal matrix with embedded isolated dielectric inclusions. In this mixture, the topological resonances of the system do not induce additional absorption in the spectral range where tuning is required. A metal matrix with dielectric inclusions, even randomly distributed, appears as an attractive design principle for fabrication of composites for tunable near-field superlens and for other metamaterial applications, where tailoring of the real part of the effective dielectric function is desirable, keeping at the same time a small imaginary part.

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