Effect of short-range order vs. long-range disorder on the effective properties of a 1D "metamaterial" chain of resonant particles

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Abstract The role of disorder in artificially-engineered materials poses important questions in regard to their interaction with light **[1-4]**. Such kind of queries comes into play most overtly in chemical self-assembled metamaterials **[5]**, where short-range, positional order is kept but long-range disorder pervade the whole crystalline structure, mainly due to grain boundaries, stacking faults, and so on. As a result, effective parameters describing the composite in the long-wavelength limit suffer from unexpected changes due to these features. Because of that, assessing the actual ability of the formers to show an exotic response to radiation (negative refraction, near-zero behavior, artificial magnetism, etc) is a must.

To account for that, and as a starting point of analysis, we propose a 1D toy model in the quasi-static regime to study the effect of correlated spatial disorder on the effective parameters of these composites **[6]**. Although this approach is rather limited, and does not provide with a bulk effective response, it gives indeed a meaningful quantity describing the averaged response of the 1D model, the external susceptibility. Moreover, we have modeled the deviations of periodicity as a block-like disorder which imposes crystalline short order but gives long range fluctuations (*Figure 1*), hence mimicking what happens in real 3D structures. In fact, we believe there is room to refine this approach, allowing both multipolar and spatial dispersion effects in modelling 3D composites **[7]**..

Thus, we will study the dependence on both filling fraction and correlation length in the response of one-dimensional chains of high-permittivity particles at Thz frequencies. These particles show a strong Mie magnetic resonance at these frequencies, opening the venue to get artificial magnetism if they are used as subwavelength resonators in 3D composites. Besides, we will analyze modifications in key features of the resonant response (amplitude, width, etc.). As main results of this investigation, we have found a regime transition in the electromagnetic response for a filling fraction around 50% *(Figure 1)*. Last, but not least, we have identified a boundary in the k-space of those modes living in the chain, which splits them into bright (coupled) modes to the impinging field and dark ones. We believe it entails a mobility edge, which can be significant to ascertain whether the composite can be described as an homogenized media.

References

[1] K. Aydin, K. Guven, N. Katsarakis, C. M. Soukoulis, and E. Ozbay, “Effect of disorder on magnetic resonance band gap of split-ring resonator structures,” Opt. Express 12, 5896–5901 (2004).

[2] A. A. Zharov, I. V. Shadrivov, and Y. S. Kivshar, “Suppression of left-handed properties in disordered metamaterials,” J. Appl. Phys. 97, 113906 (2005).

[3] X. P. Zhao, Q. Zhao, L. Kang, J. Song, and Q. H. Fu, “Defect effect of split ring resonators in left-handed metamaterials,” Phys. Lett. A 346, 87–91 (2005).

[4] M. V. Gorkunov, S. A. Gredeskul, I. V. Shadrivov, and Y. S. Kivshar, “Effect of microscopic disorder on magnetic properties of metamaterials,” Phys. Rev. E 73, 056605 (2006)

[5] V. Ponsinet, A. Aradian, P. Barois, and S. Ravaine,“Self-assembly and nanochemistry techniques for the fabrication of meta materials” in Metamaterials Handbook: Applications of Metamaterials , F. Capolino, ed. (CRC Press, 2009), Vol.2

[6] J.M.Rico-García, J.M.López-Alonso, A.Aradian ,”Toy model to describe the effect of positional blocklike disorder in metamaterials composites” JOSA B, Vol. 29, Issue 1, 53-57 (2012)

[7]C. Noguez and R. Barrera, “Multipolar and disorder effects in the optical properties of granular composites,” Phys. Rev. B 57, 302–313 (1998).

Figures

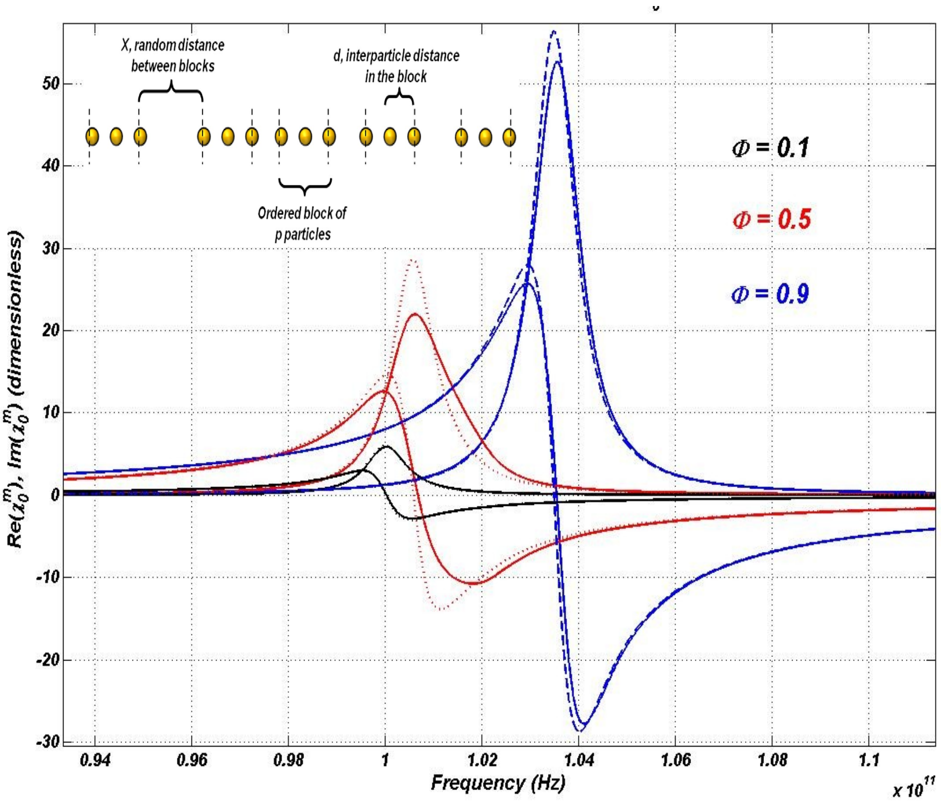

*Figure 1: Imaginary part of the external susceptibility**[6,7]** as the filling fraction increases in the 1D chain. Inset: 1D block-like disorder model. Particles are arranged in blocks where both the interparticle distance and the number of particles per block is fixed. In contrast, the interblock distance is a random variable Continous curves refers to disordered chains made of blocks of two particles (dimers), whereas dotted lines regards chains made of blocks of ten particles (decamers) **[6]***