Twists and shifts make nonlinear metamaterials

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Recent studies have demonstrated that it is possible to modify the properties of metamaterials by electromagnetic waves via inducing mechanical deformations of samples and therefore changing material properties. As an example, optical rotation of chiral particles was demonstrated [1], and a rich variety of nonlinear behaviour was achieved with magneto-elastic metamaterials [2]. The range of possible effects achievable in this way promises to be richer than in the prominent area of optomechanics, because the greater flexibility in metamaterial design overcomes the limits of available material functionalities, and offers wider possibilities for optimisation. At the same time, the implementation of magnetoelastic metamaterials [2] remains challenging and in some cases, such as the conformational nonlinearity in resonant spirals, remains inaccessible for optics. The reason for this is that the magnetic forces, employed in the initial designs, are relatively weak, so such materials require either high power or extremely small elastic restoring forces, which poses a considerable manufacturing challenge. We recall, however, that earlier research on structurally tunable metamaterials [3] indicated that near-field interaction may significantly improve the tunability range and leads to various effects associated with near-field coupling.

Here, we extend earlier approaches and propose a new concept of torsional metamaterials, by exploiting rotation of structural elements. We expect that the most efficient approach to implement dynamic coupling between electromagnetic and mechanical effects should rely on near-field interaction where both the electric and magnetic fields are involved. Near-field effects can have a powerful influence even for subtle changes in the mutual orientation. Instead of a considerable displacement of an entire array, as required for quasi-static tuning, it is sufficient to move the crucial parts of the resonant particles with respect to each other — for example, the gaps of the two coupled split-ring resonators (see Fig. 1), which involves a more gentle geometric alteration.

To describe the effect, we develop a theory based on near-field interaction to model coupled electromagnetic and mechanical properties of such system [3], and predict bistable behaviour. We fabricate a pair of split-ring resonators and perform a pump-probe microwave experiments. We measure the spectral response of the sample for different pump strength, see Fig. 2. The structure shows giant nonlinear resonance shift, and the predicted evolution from bistable to monotonic nonlinearity is clearly observed when the pump frequency approaches the initial resonance; the results show a good agreement with full wave numerical simulations.

Our results demonstrate that a novel concept of torsional metamaterials is feasible, and it would allow creating metamaterial structures with giant nonlinearity and optical activity.

Fig. 1. Metamaterial atom which components can rotate with respect to each other

Fig. 2 Resonant frequency of the meta-atom as a function of incident wave power (in dBm).

References.

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