FROM ELECTRONIC TO ELASTIC NONLINEARITY IN METAMATERIALS

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Nonlinear microwave metamaterials

- Nonlinear response due to nonlinear (diode) insertions
- Effect can be extended to higher frequencies by using nonlinear dielectrics

Appl. Phys. Lett. 95, 084102 (2009)  
Nonlinearity of Fishnet infiltrated by LC

Graph showing the transmitted power (mW) vs. incident power (mW) for different conditions:
- 0V (a)
- 40V (b)
- 0V reheated (c)
- 40V reheated (d)

Images depict prior to heating and after heating for 0V and 40V conditions.
Nonlinear properties achieved by inserting varactor diodes into the stripes.

Effect is stronger near the linear resonance.

12 orders of magnitude stronger NLOA than in natural optical crystals.

New J. of Physics 13, 033025 (2011)
New concept for nonlinearity

- Nonlinear response comes from material properties
- Can we create nonlinear response “artificially” as we create magnetism using non-magnetic elements?
- Need the structure to change with wave intensity
Response of the metamaterial is controlled by changing the arrangement of elements

\[ \mu_{zz}(\omega) = 1 - \frac{A\omega^2}{\omega^2 - \omega_r^2 + i\Gamma\omega} \quad \text{with} \quad \frac{\omega_r}{\omega_0} = \left( \frac{L \Sigma}{L} + \frac{\mu_0 n S^2}{3L} \right)^{-1/2} \]

**Structural tunability in metamaterials**

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Linear elements + linear elasticity = nonlinear mutual interaction!

\[ F_I = \frac{\mu_0 I^2}{2\sqrt{4 + b^2}} \left( \frac{\varepsilon (2 + b^2)}{b^2} - \mathcal{K} \right) \approx \frac{\mu_0 I^2}{2b} \]

\[ \beta(b) \cdot F_I(b, I) + kr_0(b - b_0) = 0. \]

\[ [Z + i\omega\mu_0 r_0 \Sigma(a, b)] \cdot I = -i\omega\pi r_0^2 \mu_0 H_0 \]
Bistable response

(a) Magnetization vs. Incident $H_0$, A/m
(b) Magnetization vs. Incident $H_0$, A/m
(c) Magnetization vs. Incident $H_0$, A/m
(d) Magnetization vs. Incident $H_0$, A/m

Acting forces, a.u.

Lattice distance $b$

0 0.2 0.25 0.3

0 1 2
Frequency dependence
Experimental observation of structural nonlinearity

- Two SRRs suspended 1.5mm apart in rectangular waveguide
- Pump-probe experiment with varying power of the pump
- Clear resonance shift with increasing pump power

Lapine et al. Arxiv (2011)
• Design of nonlinear and tunable electric, magnetic and chiral properties using nonlinear inclusions

• Structural tuning with continuous control over parameters

• Using metamaterial to design nonlinear response: magneto-elastic metamaterials
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