DTU Library

Geometrical tuning of nanoscale split-ring resonators

Jeppesen, Claus; Kristensen, Anders; Xiao, Sanshui; Mortensen, Asger

Published in:
2010 Conference on Lasers and Electro-Optics (CLEO) and Quantum Electronics and Laser Science Conference (QELS)

Publication date:
2010

Document Version
Publisher's PDF, also known as Version of record

CFM5.pdf

Geometrical tuning of nanoscale split-ring resonators

Claus Jeppesen, Anders Kristensen
Department of Micro- and Nanotechnology, DTU Nanotech, Technical University of Denmark, DK-2800 Kongens Lyngby, Denmark
Corresponding author: anders.kristensen@nanotech.dtu.dk; Phone: +45- 4525 6331, Fax: +45- 4588 7762

Sanshui Xiao, N. Asger Mortensen,
Department of Photonics Engineering, DTU Fotonik, Technical University of Denmark, DK-2800 Kongens Lyngby, Denmark

Abstract: We investigate the capacitance tuning of nanoscale split-ring resonators. An *LC*-model predicts a simple dependence of resonance frequency on slit aspect ratio. Experimental and numerical data follow the predictions of the *LC*-model.

OCIS codes: (160.3918) Metamaterials, (250.5403) Plasmonics

1. Introduction

Metamaterials are artificially structured materials with exceptional optical properties inherited from the structure of the sub-wavelength, mesoscopic unit-cell. Designing negative index materials with simultaneously negative permittivity ε as well as a negative permeability μ is one of the promising aspects of metamaterials. Since a negative electric response is common in metals at e.g. optical frequencies, the search has primarily focused on designing structures with a negative magnetic response. Different types of split-ring resonator (SRR) geometries [1–3] are particularly central in this context and have been realized at Terahertz [1, 4] to visible frequencies [3, 5].
The analogy with inductor-capacitor (*LC*) circuits have motivated considerable efforts in establishing simple circuit models, allowing for an estimate of the resonance frequency $\omega_0 = 1/\sqrt{LC}$ in terms of geometrical parameters of the split-ring resonator structure, see. e.g. Refs. [6–7] and references therein. The *LC*-model has proven to be a good approximation as long as the coupling response of the SRR array is small compared to the response of a single SRR, hence the period Λ has to be sufficiently large [8]. Tuning of the resonance has been accomplished by scaling of a single geometrical dimension [9], linear scaling of all SRR dimensions [5], and finally by altering the cladding [10].

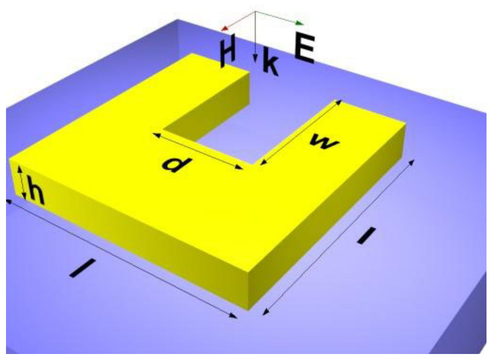

Figure 1. Schematic drawing of the split-ring resonator design, indicating central geometrical parameters as well as the polarization configuration of the excitation.

In this paper, the influence on resonance frequency of geometrical scaling of split-ring resonators is studied experimentally and by means of full-wave numerical simulations. The SRRs are placed in a periodic array keeping the period constant and large, Λ=500 nm, to minimize coupling effects. The system is described by an *LC*-model [7]. The model predicts a data collapse, which is experimentally verified.

$$(k_0 l)^2 \sim d/w \qquad (1)$$

where k_0 is the free-space wave number, l is the side length, d is the slit width, w is the slit length, see Fig. 1.

978-1-55752-890-2/10/$26.00 ©2010 IEEE

2. Results

The LC-model is compared to experimental and numerical simulation data. Full-wave simulations were performed in CST Microwave Studios. The numerical data in Fig. 2(b) are calculated for a structure with *l*=200 nm, *d*=80 nm, *h*=30 nm, Λ=440 nm. The numerical data support the predicted linear scaling of the *LC*-model.

For the experimental investigations, 8 samples with 2 mm by 2 mm arrays of gold SRRs were fabricated on glass substrates by electron beam lithography and lift-off [7], see Fig. 2(a). The geometrical parameters of the samples covered: *d*=80 nm, *w*=90-110 nm, *l*=200 nm, *h*=35 nm.

The transmission was measured using a 1 mm diameter laser spot, thus effectively probing an ensemble of 10^8-10^9 SRRs. The experimental data are fitted to the *LC*-model in Fig. 2(b), using $k = 2\pi/\lambda$, where λ is the measured resonance wavelength λ, and the split ring dimensions *d*, *l*, *w* are measured by SEM inspections.

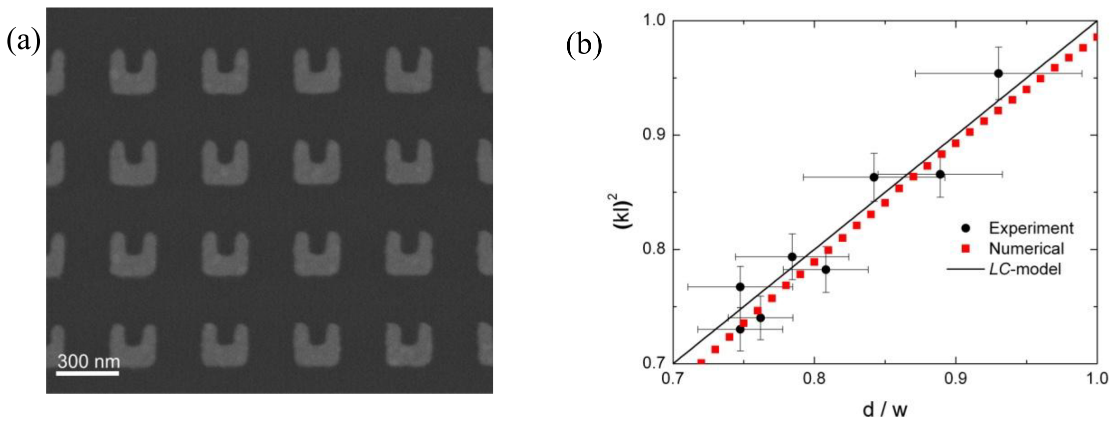

Figure 2. (a) Micrograph of a SRR array with pitch Λ = 440 nm. This sample has *l* = 200 nm, *w* = 95 nm, *d* = 80 nm, and *h* = 35 nm. (b) Plot of $(k_0 l)^2$ versus *d/w* where experimental and numerical data are plotted together with the *LC*-model. The x-error bars on the experimental data represent the standard deviation (SD) of ten individual measurements of w, and d added together. The y-error bars are the 1 nm spectral resolution of the Ando AQ-6315E Optical Spectrum Analyzer added to the SD of ten measurements of the length.

In conclusion, we have fabricated periodic arrays of subwavelength, nanoscale split-ring resonators to investigate geometrical tuning. Our key observation is that the experimental and numerical data follow the predictions of the *LC*-model.

[1] T. J. Yen, W. J. Padilla, N. Fang, D. C. Vier, D. R. Smith, J. B. Pendry, D. N. Basov, and X. Zhang, "Terahertz magnetic response from artificial materials", Science **303**, 1494 (2004).

[2] N. Katsarakis, G. Konstantinidis, A. Kostopoulos, R. S. Penciu, T. F. Gundogdu, M. Kafesaki, E. N. Economou, T. Koschny, and C. M. Soukoulis, "Magnetic response of split-ring resonators in the far-infrared frequency regime", Opt. Lett. **30**, 1348 (2005).

[3] C. Enkrich, M. Wegener, S. Linden, S. Burger, L. Zschiedrich, F. Schmidt, J. F. Zhou, T. Koschny, and C. M. Soukoulis, "Magnetic Metamaterials at Telecommunication and Visible Frequencies", Phys. Rev. Lett. **95**, 203901 (2005).

[4] S. Linden, C. Enkrich, M. Wegener, J. F. Zhou, T. Koschny, and C. M. Soukoulis, Magnetic response of metamaterials at 100 terahertz", Science **306**, 1351 (2004).

[5] M. W. Klein, C. Enkrich, M. Wegener, C. M. Soukoulis, and S. Linden, "Single-slit split-ring resonators at optical frequencies: limits of size scaling", Opt. Lett. **31**, 1259 (2006).

[6] T. D. Corrigan, P. W. Kolb, A. B. Sushkov, H. D. Drew, D. C. Schmadel, and R. J. Phaneuf, "Optical plasmonic resonances in split-ring resonator structures: an improved LC model",Opt. Express **16**, 19850 (2008).

[7] C. Jeppesen, N. A. Mortensen, and A. Kristensen, "Capacitance tuning of nanoscale split-ring resonators",Appl. Phys. Lett. **95**, 1931084 (2009).

[8] B. Kante, A. de Lustrac, and J. M. Lourtioz,"In-plane coupling and field enhancement in infrared metamaterial surfaces", Phys. Rev. B **80** (2009).

[9] K. Aydin, I. Bulu, K. Guven, M. Kafesaki, C. M. Soukoulis, and E. Ozbay, "Investigation of magnetic resonances for different split-ring resonator parameters and designs", New J. Phys. **7**, 1367 (2005).

[10] Y. Sun, X. Xia, H. Feng, H. Yang, C. Gu, and L. Wang, "Modulated terahertz responses of split ring resonators by nanometer thick liquid layers", Appl. Phys. Lett. **92** (2008).