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Simulation and Optimization of Magnetic Field Actuated MEMS-Based Metasurface for Terahertz Applications

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Summary:

A device based on a terahertz metasurface built from a split ring resonator array is presented. In the proposed device, part of the structural element is anchored in a silicon substrate, while the other part is movable (cantilever) and can be deformed using an external magnetic field of various intensities. Such a MEMS system, due to its variable geometry, constitutes a reconfigurable resonant structure that can be utilized e.g., as a sensor, based on detecting changes in the refractive index. In this work, the geometry of such a device is proposed, analyzed using numerical modeling and optimized.

Keywords: FEM simulation, metasurface, terahertz frequency, MEMS, magnetic actuation

Introduction

Metamaterials (MM), due to the possibility of obtaining electromagnetic (EM) properties not found in nature, and unique possibilities of interaction with a propagating EM wave, constitute a very interesting and rapidly developing technology widely used in sensors. The two-dimensional version of MM, called metasurfaces (MS) is relatively easy to fabricate (compared to MMs) and can be realized by thin-film fabrication techniques like surface-micromachining.

Such MS find many various applications in fields like telecommunication, sensors, selective absorbing structures, polarizers, surface wave control devices, and imaging systems [1]. The usage of MS in sensing is based on detecting changes in the refractive index (n) of the analyte. MS, as a resonant structure, is affected by varying n in the vicinity of electric field concentration areas, e.g., in capacitive gaps between conductive parts of structural elements [2].

Magnetic Field Tunable THz Metasurface

In this study, we present a THz-MS built from a split ring resonator (SRR) array. In the proposed device, part of the structural element is anchored to a silicon substrate (Fig. 1), while the other part is movable (cantilever, CL) and can be deflected using an external magnetic field of different intensity (contrary to electric field driven solutions [2]). Such a system, due to its variable geometry, constitutes a reconfigurable resonant structure with variable electromagnetic parameters (for a propagating THz pulse), and has potential for sensing the dielectric properties of the analyte.

MEMS Design and Technology

Surface micromachining with sacrificial layer technique is used to realise the CLs. It consists of two layers: A high electrical conductivity (σ) layer (Aluminum (Al)) for THz-shielding and a high magnetic permeability (μ_r) layer for bending in applied magnetic field ($\vec{B}$). Spray coated iron (Fe), sputtered Fe and nickel were investigated. Spray coated Fe has low surface-uniformity due to particle cluster formation (Fig. 2a - inset) and high carbon and oxygen concentration and hence smaller μ_r than pure Fe (Fig. 2a). Sputtered Fe layers are uniform and homogeneous however, show oxidation (Fig 2b, c) which reduces μ_r. Additionally, with increasing CL film thickness, the intrinsic stress dominates resulting in CL deformation and crack generation. Hence, an optimized fabrication process to reduce oxidation, stress and achieve high μ_r and σ layers is required and will be presented.

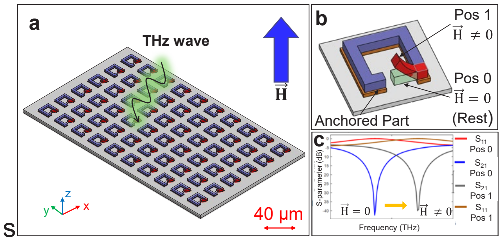

Fig. 1. Concept of MEMS metasurface actuated using magnetic field (a) SRR-based single structural element actuation (b), deflection caused resonant frequency shift (c).

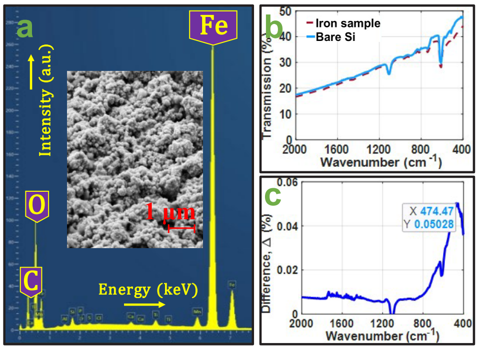

Fig. 2 a) EDX analysis spray coated Fe. The spectrum shows oxygen concentration at 27.22 Wt% and carbon at 22.1 Wt%. Cantilever surface with clusters (inset). b) FTIR transmittance: Fe sputtered silicon wafer (Si) and bare Si. c) The difference of both transmittances, Δ shows a peak at 474.47 cm^{-1} indicating iron oxide (Fe_2O_3) formed.

Numerical Model

For investigation of magnetic deflection of CL, a 2D-numerical model was developed. This model incorporated a permanent magnet (PM) and a CL in its vicinity, featuring fixed geometric and material parameters. Preliminary experiments indicated that a local $\vec{B}$ of approximately 0.1 T is necessary to induce a noticeable CL-deflection. Consequently, the remanence of the magnet was chosen to provide 0.1 T at the CL's.

The magneto-mechanical behavior was studied using the COMSOL software suite. The proposed model was employed to examine critical experimental parameters, including the CL's geometric dimensions, the type of magnetic material selected, its location relative to the magnet, and the material selected. Fig. 3 presents an exemplary result for the CL-deflection with fixed dimensions (length = 100 µm, thickness = 0.4 µm (Al: 0.3 µm, magnetic layer: 0.1 µm) with two different magnetic materials: soft iron (μ_r= 1000) and permalloy (μ_r = 10,000).

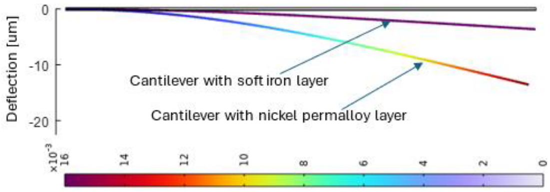

Fig. 3. The cantilever deflection in the magnetic field.

The CL with a soft iron layer achieved a maximum deflection of approximately 4.3 µm, whereas the CL with permalloy reached about 15.2 µm. This significant difference in bending can be attributed to the higher μ_r of permalloy, which enables a stronger magnetic response under the same excitation conditions.
The deformed geometry (shape of the CL profile) is then transferred to a 3D model, solving the high-frequency EM problem. The model uses periodic boundary conditions applied to the side walls to reduce computational complexity. This enables the analysis of just one element and obtaining the result for an infinite matrix of structural elements.

Results and Conclusions

An exemplary frequency response obtained for single CL-MS is shown in Fig. 4. Two resonances can be observed and utilized for sensing. The output of MS (a resonant sensor) will be the resonant frequency change (f_{R1} and f_{R2}) shown in Fig. 5 for single and double CL structures. Initially, f_{R1}, f_{R2} vary quasi-linearly and reach saturation at higher values. The magnetic field deformable metasurfaces can be utilized for reconfigurable sensors of thin film analytes. More results will be presented on the conference.

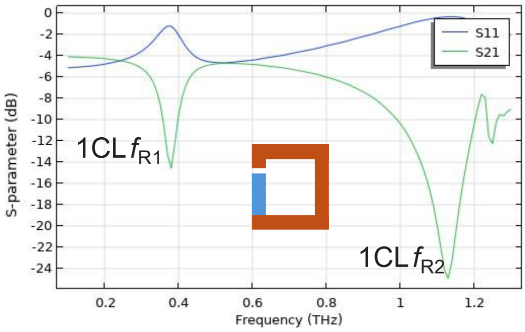

Fig. 4. Simulated Frequency response of single cantilever based metasurface (1CL) with two resonances (f_{R1} and f_{R2}); H=0.

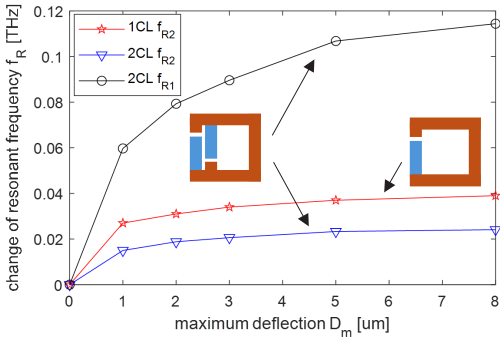

Fig.5 Change of resonant frequency caused by various levels of deflection by magnetic field for single and double cantilever structural elements.

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