Optimization of Wide-Bandpass Filter within the Terahertz Frequency Regime

S. Genovesi[1,3], T.-J. Yen[2], A. Monorchio[1], E. Prati[3], Y.-J. Chiang[2], F. Costa[1]
[1]Dip. Ingegneria dell'Informazione, University of Pisa, Pisa, Italy;
(simone.genovesi, a.monorchio, f.costa)@iet.unipi.it
[2]Dep. Materials Science and Engineering, National Tsing Hua University, Hsinchu, Taiwan;
tjyen@mx.nthu.edu.tw, d9531581@oz.nthu.edu.tw
[3]Istituto per la Microelettronica e i Microsistemi, Consiglio Nazionale delle Ricerche (CNR), Agrate Brianza, Italy;
enrico.prati@cnr.it

Abstract— Passband filters in the THz frequency range devices are one the most useful application of metamaterials to cover the so called THz gap. A design procedure to obtain THz filters with a broad transmission bandwidth is proposed. We apply the powerful and versatile Periodic Method of Moment (PMM) to evaluate the response of the metamaterial. The design is optimized by adopting a genetic algorithm to reach the target filter performance at a passband frequency centered at 1.25 THz. Two different solutions based on a single and a double frequency selective surface based on a low cost mylar substrate are compared. Herein we also plan to fabricate our design by applying UV-photolithography process to demonstrate the excellent performance.

1. Introduction

Metamaterials are artificially constructed structure which enable revolutionary electromagnetic properties hardly achieved by bulk materials [1],[2] and have increasingly generated a great interest over the past years. They typically consist of sub-wavelength metallic inclusions embedded within or on top of a substrate material. These materials have promoted the study of new state of the art devices operating in a wide range of applications [3]-[5]. Metamaterials, originally conceived in the microwave range, have later been adapted to the Terahertz [6],[7] and visible frequency range. An emerging attention in Terahertz radiation has fostered the research in order to provide materials capable to respond to Terahertz radiation since one of the greatest obstacles in the field is the lack of materials naturally well-responding at these frequencies [8],[9]. Thus, metamaterials seem to offer a solution to the problem of the "Terahertz gap" due to difficulties of an efficient electromagnetic interaction. However, within this frequency regime the fabrication process required by such short wavelengths is challenging. Moreover, when the operating frequency is close to the visible range, metals begin to deviate from the ideal perfect conductor behavior and the energy dissipation cannot be neglected in designing metamaterials. Within this framework ,there is an increasing interest in designing narrowband filters with a sharp bandstop response or wideband filters with a flat band-pass response to be employed in THz devices [10],[11].

In this work a design procedure to obtain THz pass-band filter with a broad transmission bandwidth is proposed. In particular, a Periodic Method of Moment (PMM) is employed for evaluating the response of structure under analysis and an optimization algorithm is used to improve the design in order to reach the desired filter performance.

As part of the ongoing work, a brief description of the fabrication process under test is also provided.

2. Analysis and optimization process

The considered stackup for the design comprises a single or double Frequency Selective Surface (FSS) printed on Mylar dielectric layers (ε_r=2.89). The frequency and angular response of this structure can be evaluated by using a PMM [12] which can also take into account the presence of losses in the patterned metallic periodic surface.

Our aim is to design a band-pass filter with a target level of transmission higher than an arbitrary threshold on the widest possible bandwidth. In order to accomplish this task we recur to evolutionary algorithms such as Genetic Algorithm (GA) or Particle Swarm Optimizator (PSO) which have been successfully applied for the design of metamaterials at microwave frequencies [13]-[15]. In the case of the GA, all the parameters which require optimization, namely, the kind and the thickness of each dielectric layer, the periodicity of the surface and the shape of the unit cell element, are encoded into a binary-encoded chromosome. The chromosome represents a design that could satisfy the imposed requirements in terms of, for example, reflection bandwidth and rejection level, angular stability of the frequency response or multiple bands of resonance. The value of the dielectric layer and thickness of the substrates can be chosen within the one collected in a database in order to provide realistic and feasible designs. The shape of the unit cell of the FSS is encoded by using a binary mask (Fig. 1) where '1' means presence of metal and '0' is associated to only dielectric.

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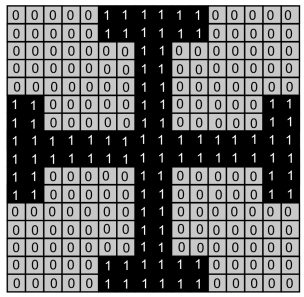

Figure 1. Example of the binary encoding of the unit cell in the optimization performed by using the Genetic Algortihm.

The frequency behavior of the FSS is efficiently calculated by using the PMM which provides data for the evaluation of the fitness function. This function ranks the best individuals and select those that will contribute to the mating for the following generation until the requested criteria are met.

3. Preliminary results – design of a pass-band filter with a wide transmission band

As a preliminary task, a band-pass filter comprising only a single FSS has been considered. In particular, the aim of this first design was to obtain a filter with a level of transmission higher than 0.4 in a band between 1.0 THz-1.5 THz. One of the configuration obtained by performing the GA optimization is the one illustrated in Figure 2. The periodicity of the unit cell is equal to 102 μm and it is suitable to be printed on a 12 μm–thick Mylar substrate.

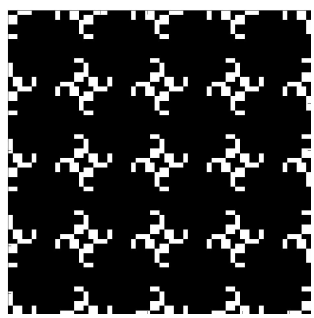

Figure 2. Spatial filter with a rotated four-fold symmetry as a result of the optimization performed by the genetic algorithm.

The frequency response is reported in Figure 3. The bandwidth at a transmission level is higher than 0.4 goes from 1.0 THz to 1.65 THz. In order to improve the flatness of the filter and to enhance the steepness of the transition between the bandpass region and the total reflection, the case of a design with two FSSs has been analyzed and optimized.

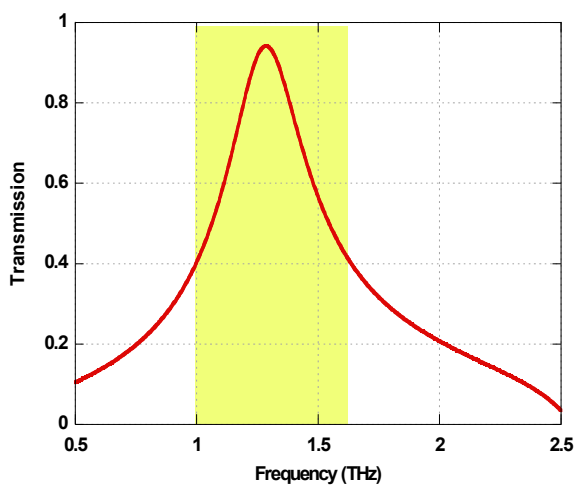

Figure 3. Transmission coefficient for normal incidence for the optimized screen with a single frequency selective surface.

We employed the same unit cell of the screen in (Fig.2) but with a periodicity of 84 µm and a substrate thickness of 10 µm. As it is apparent from Fig. 4 the overall bandwidth in which the transmission level is higher than 0.4 is reduced but the transition between the band-pass region and the high reflection is increased. Moreover, the top of the transmission coefficient curve is flatter and the transmission bandwidth for a level higher than 0.8 is slightly enlarged.

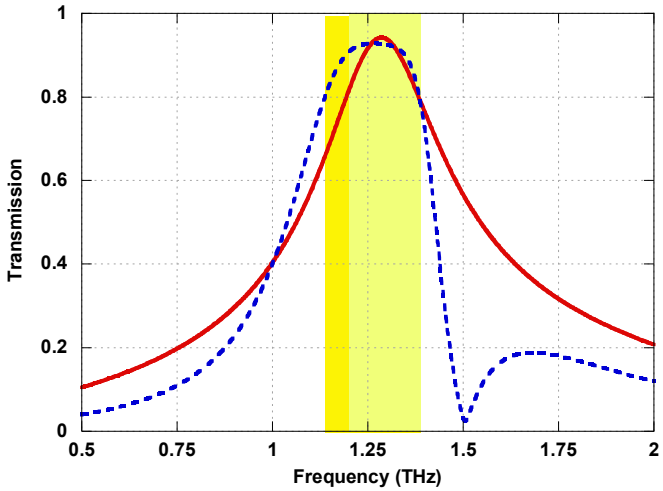

Figure 4. Comparison between the transmission coefficient for normal incidence for the optimized screen with a double frequency selective surface (dashed line) and the one with a single FSS (continuous line).

4 Fabrication process

To realize our designed THz bandpass filter, we will apply a standard UV-photolithography process to fabricate the micro-scale features on Mylar membranes, which are transparent within THz regime. First, we will spin a thin layer of positive photo resist AZ-5214E on the Mylar membrane and employ a contact aligner to define the entire structure. After developing the exposed photo resist, an adhesion layer made of 10-nm aluminum film, will be deposited on the Mylar substrate, followed by a 200-nm thick copper to construct the metallic pattern in an electron beam evaporator. It should be notice that in this process a 2-µm accuracy of alignment for a double frequency selective surface will be achieved.

5 Conclusions anf future developments

To conclude, we obtain passband filters in the THz frequency range, centered at 1.25 THz. The design procedure for broad transmission bandwidth is proposed, by adapting the periodic method of moment and the optimization provided by a genetic algorithm to reach the specific target filter performance. The employment of a standard UV-photolithography process and low loss Mylar membranes allows realizing our design with a critical feature size about 2 µm. A double FSS created from the same pattern of the single FSS passband filter exhibits similar transfer function characteristics and it is further optimized. For the ongoing project, we will fabricate real samples to realize the performance of our designed metamaterials in the THz regime.

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