Planar Two-Dimensional Negative Refractive Index Structures at THz Regions

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1. Introduction

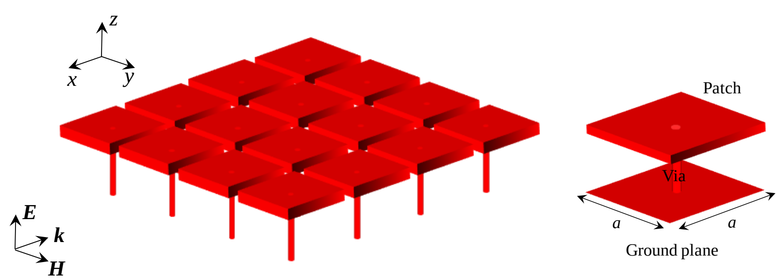
The non-resonant transmission line approach [1-3] is another route to realize a negative refractive index materials or left-handed materials [4]. By considering the duality of the equivalent circuit of the distributed transmission line [5], simultaneous negative permittivity and negative permeability can be realized by exchanging the equivalent circuit elements in the series and shunt branches with drastic wideband and low loss characteristics compared with conventional resonant type left-handed materials using the split-ring resonators and wires. Soon after the left-handed transmission line had been proposed, the concept has been extended to a more general form, the composite right/left-handed (CRLH) transmission line, taking into account the inevitable parasitic reactances in the unit cell [6,7]. In addition to the excellent performances, the CRLH transmission line approach enables us to manipulate and engineer the bandgap and impedance of the left-handed materials and gives us a full facility for design, modeling and characterization of left-handed metamaterials with physical insight. It is noted that although the structure has first demonstrated at microwave frequency region [6,7], the structure can be scalable to the THz and even optical frequency regions with an appropriate design and fabrication technology.

In this paper, a two-dimensional planar negative refractive index metamaterial operating at the THz region is designed based on the CRLH transmission line concept. The metamaterial is a planar two-dimensional array of so called mushroom structures feasible for fabrication with lithography technology. The unit cell is designed and optimized to have a zero-bandgap at the Γ-point, which is capable of smooth transition between the left-handed and right-handed bands.

2. Two-dimensional mushroom structure at THz regions

Figure 1 shows the planar negative refractive index structure under consideration. The structure is a two-dimensional array of unit cells composed of a square patch, a via and a ground plane as seen in Fig. 1 (b). All the components are to be made of good conductor and the rest of the space are vacuum or can be filled with dielectrics depending on available fabrication technology. The square patch is connected with a via at the center to the ground plane.

The patch is capacitively coupled with adjacent unit cells and also has an inductive connection with the ground plane. These correspond to the negative permeability and a negative permittivity, respectively, and the structure exhibits negative refractive index property with two-dimensional propagating wave polarized in the *z*-direction.



(a) General view (b) Unit cell

Fig. 1: Two-dimensional negative refractive index mushroom structure

3. Dispersion characteristics

Dispersion characteristics of the structure are calculated with the two-dimensional periodic boundary conditions by full-wave simulation based on the finite-element method. The lattice constant is chosen as a = 37 μm. The dimension of the patch and the diameter of the via are designed to be 36 μm and 2.0 μm, respectively. It is assumed that the patch, the via and the ground plane are made of aluminum with the conductivity of 3.8×10^7 S/m and the mushroom is filled with silicon oxide with the relative dielectric constant of 4.1. The total thickness is 6.67 μm. The calculated dispersion characteristics are shown in Fig. 2. The negative slopes in the positive β regions in both the Γ-X and Γ-M paths are seen from the figure and isotropic negative refractive index characteristics of the structure are confirmed. The left-handed bandwidth in the Γ-X path is as wide as from 676 GHz to 980 GHz. The successive right-handed bandwidth is from 980 GHz to over 2 THz without a bandgap.

4. Conclusions

The two-dimensional planar negative refractive index metamaterials composed of an array of mushroom structures have been designed at THz region. The unit cell has been optimized to satisfy the balanced condition to have a zero-bandgap at the Γ-point. The structure is compatible with future planar circuits and devices with low-loss and wide-band characteristics.

References

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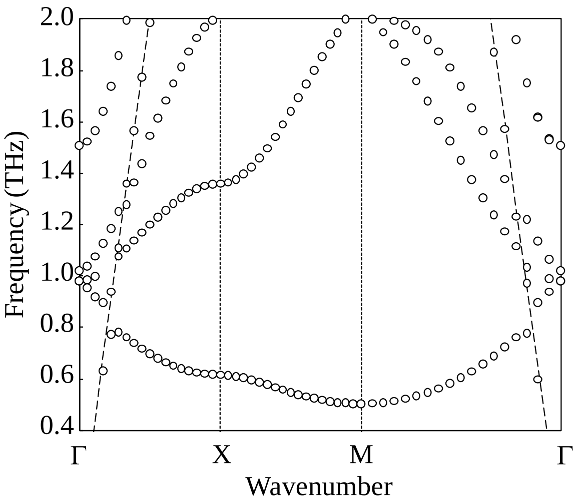

Fig. 2: Dispersion characteristics (simulation)