# Influence of Gain on Transmission of Nanocavity Containing Metamaterials

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***Abstract*—This paper studies the influence of gain on transmission of electromagnetic waves through the nanocavity placed between two reflectors. The reflectors consist of alternating nano-layered structure that contains dispersive negative and non-dispersive positive refractive index materials. Here, we analyze transmission of the structure by utilizing transfer matrix method on $10^3$ THz regime of frequency.**

***Keywords*—Nanocavity; metamaterial; multilayers; gain; transmission.**

## I. Introduction

Metamaterials are artificially media, exhibit fascinating properties which are not found in nature [1]. Metamaterials include materials with both negative $\varepsilon$ and $\mu$ named doubled negative (DNG) materials [2], [3]. Since DNGs have a negative refraction, they called negative index materials (NIMs) [1].

Recently, alternative structures containing NIMs and positive index materials (PIMs) considered by many researchers to design novel optical devices [1], [4]-[7].

In this paper we utilize two periodic structures consist of nano NIM-PIM slabs as two reflectors to design a nanocavity with a medium as defect layer composed of two nano PIM slabs which are the same together and different to the PIM slabs in the reflectors (see *Fig. 1*). Here, we investigated the transmission through this structure, and then the influence of gain on the transmission.

## II. THEORETICAL FORMULATION

For a TE wave to be incident onto a one dimensional PC at an angle $\theta_A$, the transmission coefficient is given by[8]

$$T_t = \frac{p_s}{p_A}\left|\frac{2p_A}{(m_{11}+m_{12}p_s)p_A+(m_{21}+m_{22}p_s)}\right|^2 \qquad (1)$$

Where $p_A = n_A Cos\theta_A$, $p_s = n_s\left[1-(n_A{}^2 Sin^2\theta_A / n_i{}^2)\right]^{1/2}$ and $m_{ij}$ are the transfer matrix element and is given by

$$T = [M(d)]^N [M'(d)]^M [M(d)]^N \equiv \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \qquad (2)$$

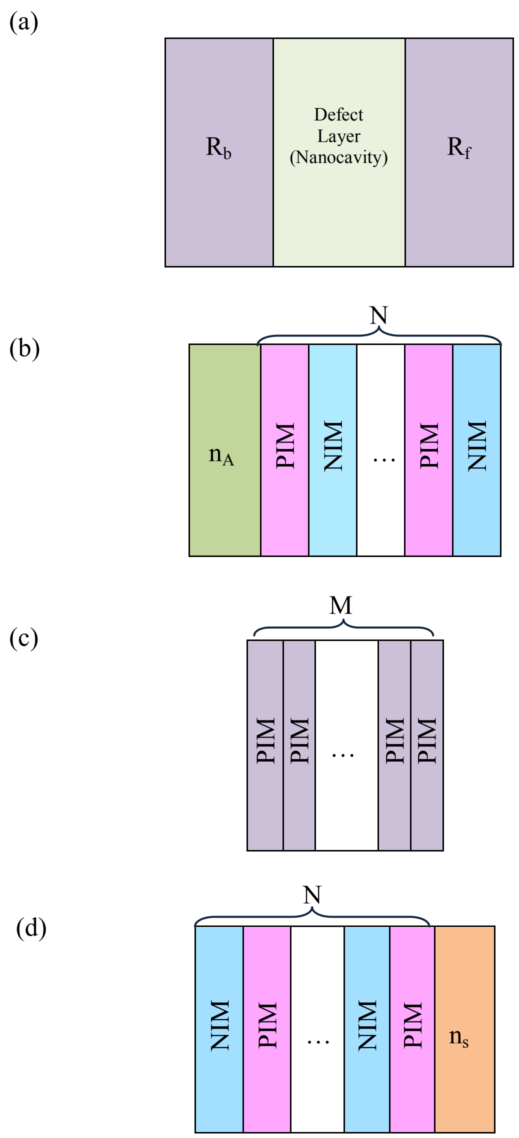


Fig. 1. (a) Schematic of the nanocavity structure under investigation, (b) The reflectore that is placed in back of Structure ($R_b$), (c) Defect layer structure and (d) The reflectore in front of Structure ($R_f$).

 

## III. Numerical Result and Discussion

We plotted transmission spectra which is shown in *Fig. 2,* by using Eq. (1), for s-polarized waves at zero angle of incidence for nanocavity which composed of two 1DPCs that contains ordered NIM-PIM slabs as reflectors and PIM-PIM layers with different media compared to the reflectors. All layers have thickness in range of nano-meter. Then, we investigated the transmission of the structure in $10^3$ (THz) range of frequency.

We suppose air as positive layers hence, $\varepsilon_2 = \mu_2 = 1$. The necessary parameters and defined as: $n_{PIMD} = 1.5$, $n_A = 1$, $n_s = 1$, $d_{PIM} = d_{PIMD} = 5.5\,nm$, $d_{NIM} = 16\,nm$, $N = 15, M = 5$. $d_{PIMD}$ and $n_{PIMD}$ denote thickness and refractive index of PIM media in defect layer as nanocavity, respectively.

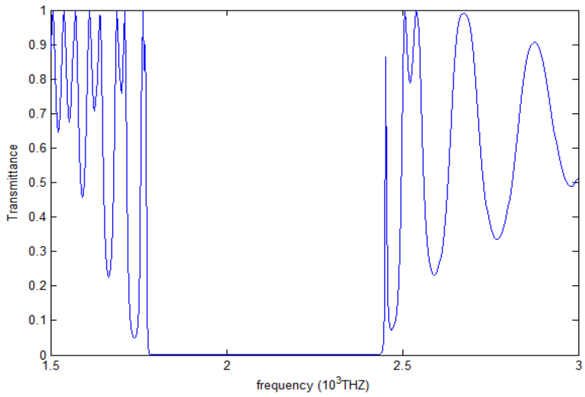


Fig. 2. Transmittance of nanocavity versus frequency.

To compensate the inherent absorption in structure, we exerted gain on defect layer. Incorporating gain on the defect layer leads to increasing transmission as it is shown in *Fig. 3*.
*Fig. 4*, shows, if the defect layer was absorptive, the transmission spectra of electromagnetic wave declines to the lower values, and bandgap expands by enhancement of absorption and whatever we move on gain axis to the gain values, the transmission spectra increase to the upper values.

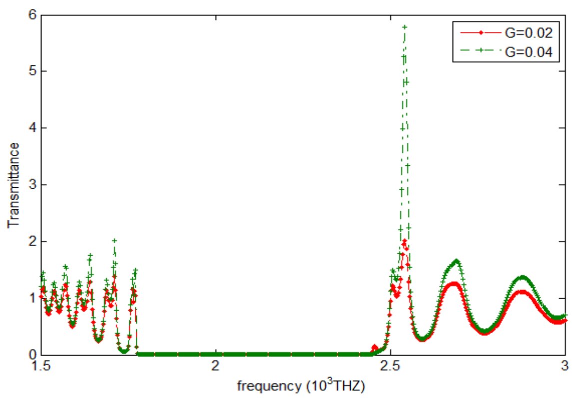


Fig. 3. Transmittance of nanocavity for various values of gain.

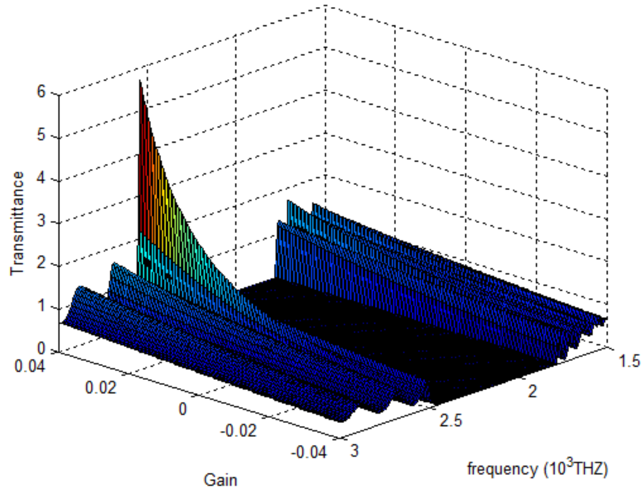


Fig. 4. A three dimension image of transmission versus the frequency and gain spectra.

## IV. Conclusion

So, we can say that by regulating system on a particular frequency and utilizing a reasonable gain, we can obtain a very high transmission in order to design a very effective nanocavity which can be used in nanolasers.

## References

[1] R. Aylo, *Wave Propagation in negative index materials*, Dissertation, Submitted to The School of Engineering of the University of Dayton, Ohio, 2010.

[2] F. Qin and H. x. Peng, "Ferromagnetic microwires enabled multifunctional composite materials," in Progress in Materials Science, vol. 58, 2013, pp. 183–259.

[3] F. Xi and L. Hu, "Omnidirectional reflectance gaps and resonant tunneling effect in a one-dimensional photonic crystal consisting of two metamaterials." Eur. Phys. J. D, vol. 66, no. 33, 2012 [Societ`a Italiana di Fisica, Springer-Verlag, 2012].

[4] R. Aylo, P. P. Banerjee, A. K. Ghosh and P. Verma, "Design of metamaterial based sensors for pressure measurement," *Proc. of SPIE*, vol. 7604, no. 760412, December 2011.

[5] C. W. Wong, S. Kocaman, M. S. Aras, P. Hsieh, J. F. McMillan, C. G. Biris, N. C. Panoiu, M. B. Yu, D. L. Kwong and A. Stein, "Negative Index Photonic Crystals Superlattices and Zero Phase Delay Lines," Photonic Crystals - Innovative Systems, Lasers and Waveguides, Dr. Alessandro Massaro, Ed. New York, ISBN: 978-953-51-0416-2, InTech, Available from: http://www.intechopen.com/books/photonic-crystals-innovative-systems-lasers-and-waveguides/negative-index-photonic-crystals-superlattices-and-zero-phase-delay-lines.

[6] T. J. Cui, D. R. Smith and R. Lio, Metamaterials. New York, Dordrecht Heidelberg London: Springer, 2010.

[7] T. Jalkanen, "Porous Silicon Optical Filters in Gas Sensing Applications," Turun Yliopisto University of Turku, Painosalama Oy - Turku, Finland, 2012

[8] M. Born, E. Wolf, "Basic properties of the electromagnetic field," in Principles of Optics, Cambridge University Press, U.K, 1980, pp. 1-70.