Thermal Impact on Metamaterial Absorber in Traveling-Wave Tube

Fuxian Zhong[1], Ningfeng Bai[1], Changsheng Shen[1], Xiaohan Sun[1], Pan Pan[2], Jun Cai[2], Jinjun Feng[2]

1. Research Center for Electronic Device and System Reliability, Southeast University
Nanjing, Jiangsu, China,210096
2. Beijing Vacuum Electronics Institution
Beijing, China, 100016

Abstract: *In this paper, the thermal impact on a metamaterial absorber (MMA) used in traveling-wave tube is investigated. This MMA has three layers, where the dielectric layer, SiC, is middle layer with metallic layers, copper, are top layer and bottom layer. The thermal impact on this MMA is studied with a comprehensive consideration of all thermal-sensitive parameter of MMA structure. The simulation results reveal the performance of MMA in a high temperature circumstances. When temperature rising from 300 K to 600 K, the absorbing frequency of the proposed MMA shifts from 27.60 GHz to 26.79 GHz. These results indicate the MMA has a potential application in TWT.*

Keywords: thermal, metamaterial absorber, traveling wave tube

Introduction

Since Landy[1] introduced the first novel metamaterial absorber (MMA) in 2008, researchers developed many advantages of MMAs: ultrathin, ultra-broadband, polarization-insensitive [2-4] and so on. Nevertheless, FR-4 and Rogers are commonly utilized as unit cell substrates possibly cannot maintain rigid and their special performance when the temperature increases from 300 K to 500 K or above. Moreover, even the conductivity of copper, silver and other resistive materials, which are used commonly in artificial patterns, probably changed by a rising temperature then lead to an invalidation of absorption. Consequently, these MMAs couldn't be applied in traveling wave tube (TWT) because of the extreme high power and temperature.

This paper presents simulation results to reveal the detrimental impact of a high ambient temperature on MMAs. This study indicates the thermal stability of MMAs should be investigated to ensure the MMA can be applied for TWT.

Design

The schematic views of the proposed design are depicted in Figure 1, in which the configuration is composed of the Copper pattern on top layer, the SiC dielectric substrate and a Copper metallic ground plane. The pattern of this MMA is shown in Figure. 1(b) as a hollow cross and the width of the metallic is labelled as G, the distance of the closed parallel line is labelled as w, and the distance of the farthest parallel line is labelled as C. The thickness of patter layer and ground layer are labelled as *t,* and the thickness of the dielectric layer is labelled as *d*. The geometrical parameters of the proposed design are presented in Table 1. The permittivity and the loss tangent of SiC versus frequency are shown as Figure 2.

Results

For actually application in TWT, the thermal stability of MMA is a basic requirement. Here, the impact of electromagnetic and thermal on MMA are simulated to study the relation between the characterization of MMA and temperature. The propagation direction of incident electromagnetic wave is perpendicular to the sample plane (along z-direction).

The absorption bandwidth represents the frequency bandwidth where the absorption greater than 90%. The performances of the proposed MA are studied at different temperature and simulation results are illustrated in Figure 2. The initial peak of resonant absorption frequency is 27.60 GHz at T0 = 300 K. And with the ambient temperature increasing form 300 K to 600 K, the peak of resonant absorption frequency shifts from 27.60 GHz to 26.79 GHz. Apparently, after T = 375 K, the greatest absorption rate gradually drops to lower than 90%. This is indicates that the position of MMA should be carefully designed to avoid to place in the high temperature area, normally at the end of TWT, where could reach to 600K. Demonstrations above obviously reveal the disadvantage of a high temperature as well as the drawback of MAs with a conventional design. In other word, at a common position where should be placed an attenuator in TWT, the temperature is varied below 400K, the MMA persist its merit used as an attenuator.

Conclusion

In summary, with a comprehensive consideration of thermal impact on both Cu and SiC, simulation results demonstrate high temperature inevitably undermine the performance of MMAs with conventional design and present an evidence that the MMA can replace traditional attenuator. In order to extend application of MMAs in VED, an improvement of the thermal stability is significant and indispensable.

References

1. N. I. Landy, S. Sajuyigbe, J. J. Mock, D. R. Smith, and W. J. Padilla, "Perfect Metamaterial Absorber," Physical Review Letters, vol. 100, p. 207402, 2008.
2. Y. Zhang, L. Yue, Y. Cao, Y. Liu, and H. Zhang, "Graphene induced tunable and polarization-insensitive broadband metamaterial absorber," Optics Communications, vol. 382, pp. 281-287, 2017.
3. Y. He, X. Wang, W. Ingram, A. I. Bin, and Y. Zhao, "Optimized Fan-shaped Chiral Metamaterial as an Ultrathin Narrow-band Circular Polarizer at Visible Frequencies," Nanotechnology, vol. 29, p. 165301, 2018.
4. Y. Huang, L. Liu, M. Pu, X. Li, and X. Luo, "Refractory metamaterial absorber for ultra-broadband, omnidirectional and polarization-independent absorption in the UV-NIR spectrum," Nanoscale, vol. 10, pp. 8298-8303, 2018.

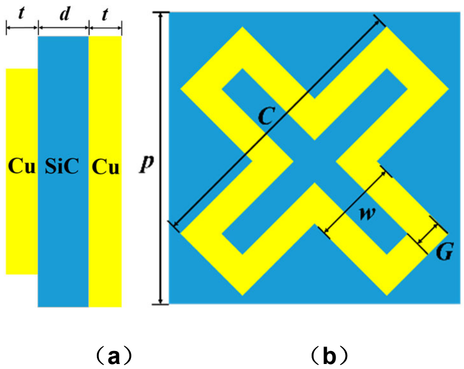

Figure 1. A unit cell: **(a)** the side view **(b)** the top view.

Parameters	*p*	*C*	*G*	*w*	*t*	*d*
Values (μm)	4750	5400	190	1100	80	510

Table 1. The geometrical parameters of the proposed

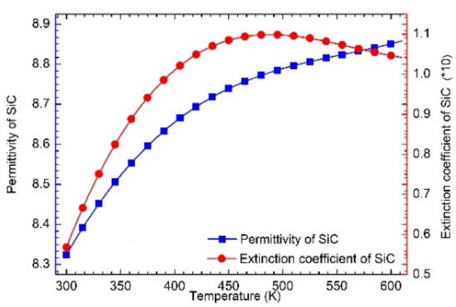

Figure 2. The real part of permittivity and the loss tangent (extinction coefficient) of SiC at 300 K to 600 K.

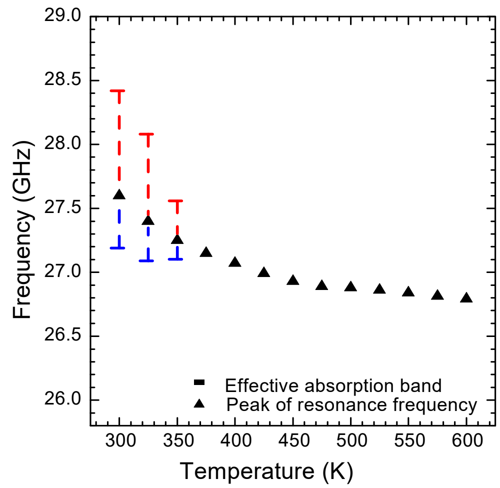

Figure 3. The effective absorption band and the peak of resonance frequency at 300 K to 600 K.