Journal of Electronic Testing (2018) 34:203–207
https://doi.org/10.1007/s10836-018-5718-9

Measurement of Nonlinear Dielectric Behaviour of Semiconductor Material Under Microwave Field in Dual-Mode Rectangular Cavity

Yong Gao[1] · En Li[1] · Gaofeng Guo[1]

Received: 20 December 2017 / Accepted: 8 March 2018 / Published online: 14 March 2018

Abstract

In this letter, a microwave cavity for investigating the effect of external microwave fields on the dielectric behavior of semiconductor material is proposed. We use a dual-mode rectangular cavity where the stimulus and test signals are supplied by two different swept frequency microwave sources. By adjusting the power level of the stimulus signal, the intensity of microwave field in the cavity is changed. Two band-stop filters are introduced to isolate the signals coming from the stimulus signal. Measurement results show that the dielectric properties of indium phosphate manifest nonlinear behavior under the electronic field intensity of 10^5V/m. From the experimental result and theoretical analysis, we conclude that the nonlinear behavior is caused by the material's inherent characteristics.

Keywords Measurement · Dielectric · Nonlinear behavior · Microwave field · Cavity

1 Introduction

Research on the measurement of dielectric property of materials is important because those properties are needed before the materials can be used. The cavity perturbation technique is the most common resonator-based approach for measurements of low loss materials [3, 4].

Due to the increasing miniaturization of microwave integrated circuits and the rapid development of high power microwave technology, the properties of the materials as affected by the external microwave field have attracted the attention of researchers. It is found that the dielectric property of polar liquids and primary alcohol mixtures changes under microwave field [5, 7]. Lots of research has been reported about ionizing radiation effects on electrical properties of dielectric materials [1, 2, 6]. An increase in the conductivity of pentacene, a kind of organic semiconducting material, is found when exposed to ionizing radiation. This is a controlled method of doping organic semiconducting materials [6]. However, the investigation of materials' dielectric property under strong microwave field is still very relevant.

In this letter, we have developed a dual-mode rectangular cavity to investigate the influence of external microwave field on the dielectric property of semiconductor material. One mode is used to create a strong electrical field, while the other mode is for measuring. In order to prevent the stimulating signal from affecting the testing signal, two band-stop filters, whose center frequencies are the same as that of the stimulating signal, are introduced. Upon measurement, the dielectric property of indium phosphate (InP) is found to slightly change under the strong electromagnetic environment, which shows that it is an inherent characteristic of the material itself than microwave heating causing the nonlinear phenomenon.

2 Design of the Dual-Mode Rectangular Cavity

A rectangular cavity was designed to have two modes, TE_{102} and TE_{103}. The former mode is used to produce a strong microwave field and the latter mode measures the

Responsible Editor: T. Xia

✉ En Li
lien@uestc.edu.cn

Yong Gao
gy_wlee@163.com

[1] School of Electronic Engineering, University of Electronic Science and Technology of China, Chengdu 611731, People's Republic of China

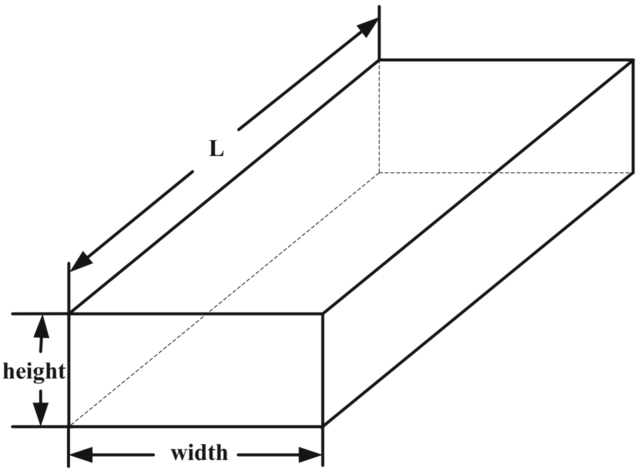


Fig. 1 A structure schematic of rectangular cavity

dielectric property with a low power signal. The structure schematic of the rectangular cavity is given in Fig. 1. By adjusting the size of the cavity, the TE_{102} and TE_{103} modes work at the frequencies around 2.45GHz and 3.13GHz respectively. The cavity parameters are as follows: width = 83.36mm, height = 43.18mm, L = 172mm.

Figure 2 shows the model of the cavity and the electric field distributions of both resonant modes in the cavity by High Frequency Simulator Structure. The electric field distributions of both resonant modes in the cavity are shown in Fig. 2. The strongest electric field of the TE_{102} mode lies at L/4 and 3*L/4 in the cavity. The strongest electric field of the TE_{103} mode lies at L/6, 3*L/6 and 5*L/6 in the cavity.

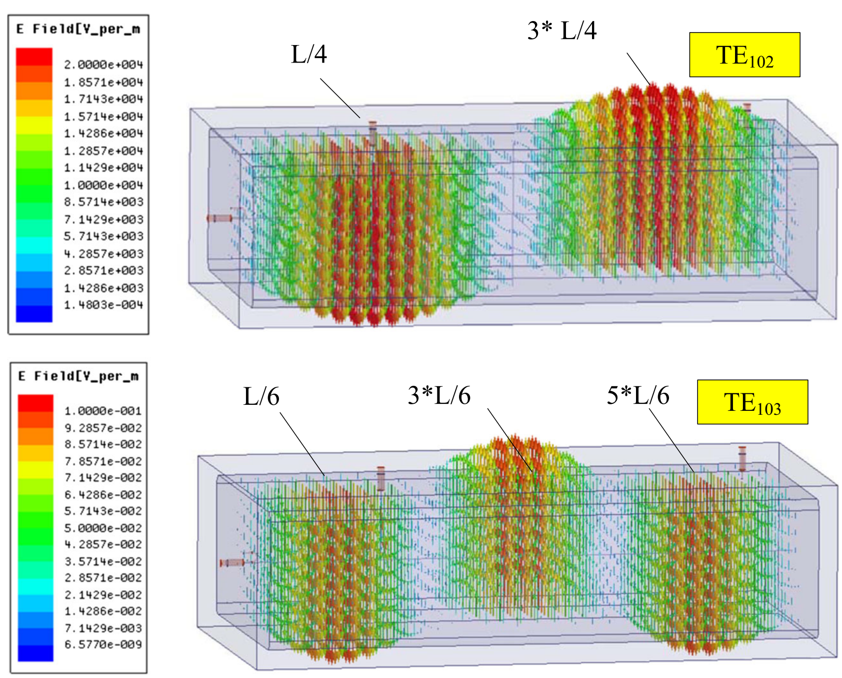
From Fig. 2, it is easy to see that if the stimulating signal is injected through a probe at L/4 of the cavity, TE_{102} will be activated. The sample under test is put at the 3*L/4 in the cavity, which is the strongest electric field location for the TE_{102} mode. If the power level of stimulating signal changes, the electric field strength around the sample will be changed too. Finally, the dual-mode rectangular cavity is fabricated and coated with silver. By adjusting the probe, a good match is achieved at the stimulating port, which ensures high power signal being injected into the cavity.

3 Experimental Setup

Using the dual-mode rectangular cavity, a test system setup is shown in Fig. 3.

The stimulating signal can be amplified by an amplifier, whose frequency is the same as that of the TE_{102} mode, and the maximum output of the amplifier is about 53dBm. The reflection between the source and the power amplifier is reduced by isolators. The testing signal is provided by the vector network analyzer (VNA), whose frequency is around the working frequency of the TE_{103}. Through a coupling loop and a probe, the testing signal is injected into and coupled out of the cavity for measuring the dielectric property. In addition, the two band-stop filters with a more than 30dB attenuation in the stop band, are introduced to isolate the signals coming from the stimulating source. The

Fig. 2 Electric field distribution of the two modes in the cavity



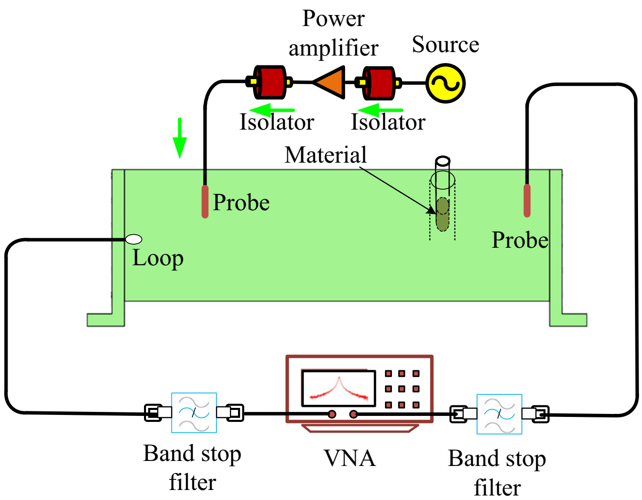


Fig. 3 Schematic of the experimental setup for nonlinearity test

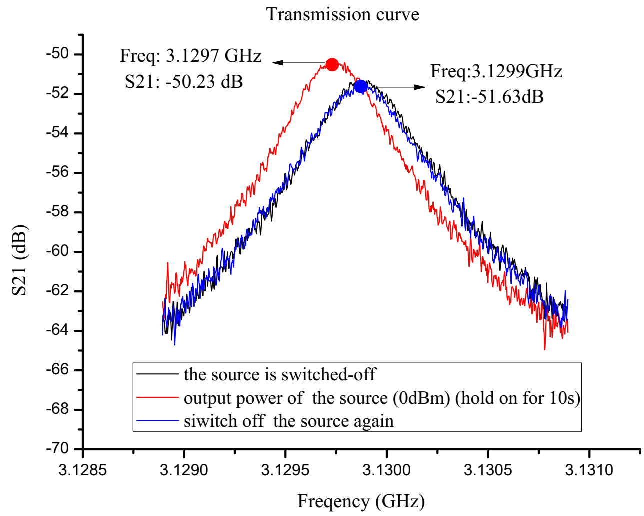


Fig. 5 Test curves of InP

center frequency of the two band-stop filters is around the frequency of the stimulating signal. The experimental setup is shown in Fig. 4.

4 Experiment and Discussion

An InP sample is placed at 3*L/4 of the cavity and the source is switched-off initially. The transmission curve of the testing signals is obtained by the VNA, shown as the black curve in Fig. 5. Then the output of the source is adjusted to 0dBm and the red transmission curve is obtained as shown in Fig. 5. Mark the red curve and hold the output of the source at 0dBm for 10s. After that, the output of the source is shut down, and the red transmission curve changes to the blue curve shown in Fig. 5.

According to the cavity perturbation method, as expressed by equations (1) and (2), the real part of the dielectric constant is determined from the shift of the resonant frequency, while the imaginary part causes the variation in the Q of the cavity [4]. Therefore, it can be easily deduced that the dielectric constant of the InP has changed at different microwave field intensities.

$$\frac{\omega - \omega_0}{\omega_0} = -\varepsilon_0(\varepsilon' - 1)\frac{\int_\Delta \vec{E} \cdot \vec{E_0}^* dV}{4W} \tag{1}$$

$$\frac{1}{Q} - \frac{1}{Q_0} = \varepsilon_0 \varepsilon'' \frac{\int_\Delta \vec{E} \cdot \vec{E_0}^* dV}{4W} \tag{2}$$

where ω and ω_0 are the angular resonant frequencies before and after the perturbation, respectively. Q and Q_0 are the quality factors before and after the perturbation. $\vec{E}$ and $\vec{E_0}$ are the electric field strengths before and after the perturbation in the cavity. W is the total store energy in the cavity. And ε' and ε'' are the real and imaginary parts of the dielectric constant, respectively.

In the experiment, the output of the source remains at 0dBm for 10s. Suppose the sample has been heated and the nonlinearity is caused by the heating. The thermal conductivity of InP is only $0.7W{\cdot}\text{cm}^{-1}\ \text{K}^{-1}$, which means that the heat dissipation of the InP sample is not very good. That is to say, after we shut down the output of the source,

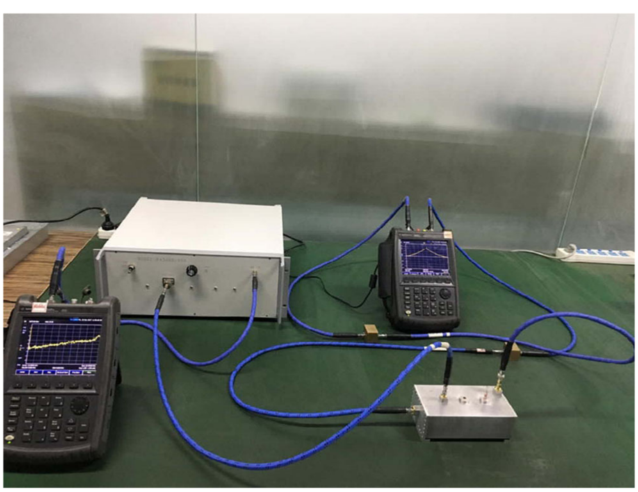


Fig. 4 Photograph of the experimental setup

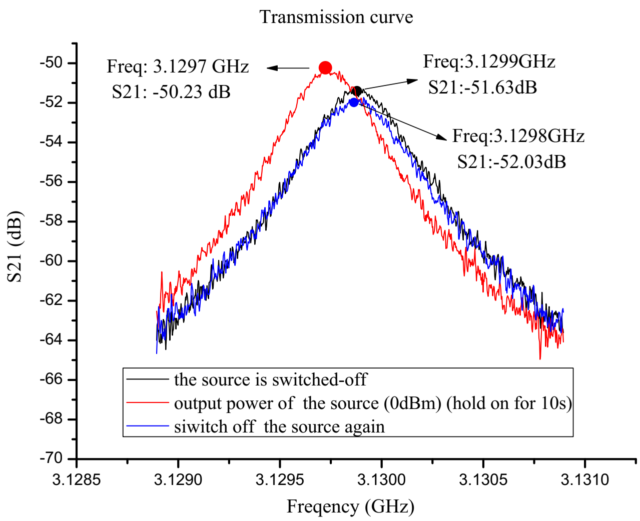


Fig. 6 Test curve of InP as the output of the source is held on at 0 dBm for 1 min

the red curve will not change to the blue one immediately. However, in the experiment, the red curve changes to the blue one immediately when we shut down the source.

To further examine the conclusion that the nonlinear behavior of the dielectric property of InP is largely caused by the material itself than by heating, an additional experiment is conducted. In the experiment, the output of the source remains at 0dBm for 1min and then the source is shut down. The results are shown in Fig. 6.

In Fig. 6, we can see that the blue curve is no longer coincides with the black one as the holding time is increased from 10s to 1min. The frequency shift starts to change with the hold time increasing. The reason is that after a longer time under microwave heating, the sample was heated a little bit, and its dielectric property changed a little bit. However, the frequency difference between the blue curve and the black curve is far less than the difference between the red curve and the black curve. Thus, we think that it is the non-thermal effect that influences the dielectric property of InP in the microwave range.

5 Conclusion

In this contribution, a new experimental method and apparatus are introduced for investigating the dielectric property of microwave semiconductor materials under microwave field through a dual model rectangular cavity. The stimulation signal and the test signal are supplied by two different frequency microwave sources. By changing the power level of the signal, the local electric field around the sample can be changed. Two band-stop filters isolate the two signals. In the experiment, more than 50W of power is injected into the cavity when the source output is 0dBm, and the electric field strength around the sample is nearly 10^5V/m. Under the strong microwave field, the nonlinear characteristic of InP is evaluated in the microwave range. Through the experimental observation, we deduced that it is a kind of non-thermal effect that causes the interaction between the external microwave field and the material.

Acknowledgments The authors acknowledge the support from the National Natural Science Foundation of China (Grant Nos. 61671123 and 61001027) and the Open Foundation of National Engineering Research Center of Electromagnetic Radiation Control Materials (ZYGX2016K003-7).

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Yong Gao received the M.S. degree in electronic engineering from the University of Electronic Science and Technology of China (UESTC), Chengdu, P.R. China, in 2013, where he is currently working toward the Ph.D. in electro-magnetic parameters measurement of materials. He is currently with the University of Electronic Science and Technology of China, where he is a Ph.D. student with the National engineering Research center of Electromagnetic Radiation Control Materials, School of Electrical Engineering. His research interests include nonlinear dielectric properties of high power microwave material, high power devices feature parameter extraction, passive intermodulation test technology, design of microwave devices, and microwave integrated circuits.

En Li received the M.S. degree in physical electronics and the Ph.D. degree in electromagnetic field and microwave technology from the University of Electronic Science and Technology of China, Chengdu, PR China, in 2003 and 2009, respectively. In 1997, he joined the faculty of the University of Electronic Science and Technology of China. From 2005 to 2010, he was an associate professor, where he was involved in research projects in the area of electro-magnetic parameters measurement of materials, design of microwave device design, automatic microwave test system. Since 2010, he has been a professor, and he has taken charge of the research projects in the area of electromagnetic parameters measurement of dielectric materials at high temperatures and microwave plasma diagnosis. His current main research interests include microwave plasma diagnosis, electromagnetic parameter measurement of dielectric material at high temperatures, nonlinear parameter measurement of high power amplifier, design of microwave devices. He has authored or coauthored over 100 journal and conference papers. He has 12 authorized national invention patents. He was the receipt of the second prize of national science and technology progress award, the first prize, the second prize and the third prize of provincial and ministerial level scientific and technological progress awards. Dr. Li is a guest professor at National Defense Science and Technology Key Lab of Advanced Function Composite Material, a member of IEEE, a member of the standing council of National Materials New Technology Development Research Institute. He was a winner of Education Ministry's New Century Excellent Talents Supporting Plan in 2010, a reserve candidate of academic and technical leader of Sichuan Province in 2013, a receipt of the title of excellent experts with outstanding contribution of Sichuan Province in 2013.

Gaofeng Guo received the M.S. and Ph.D. degrees in physical electronics from the University of Electronic Science and Technology of China, Chengdu, PR China, in 2000 and 2008, respectively. In 2000, she joined the faculty of the University of Electronic Science and Technology of China. From 2001 to 2006, she was a lecturer, and she was involved with research projects in the area of electromagnetic parameter measurement of microwave dielectric material. Since 2006, she has been an associate professor, and she has been involved in research projects in the area of electromagnetic parameters measurement of dielectric materials, dielectric property measurement at high temperatures. Her current research interest includes electromagnetic parameter measurement of dielectric material, nonlinear parameter measurement of high power amplifier.