NONLINEAR ELECTROMAGNETICALLY INDUCED TRANSPARENCY BY INTENSED TERAHERTZ FIELD

Biaobing Jin[1]*, Caihong Zhang[1], Jingbo Wu[1], Xiaoqing Jia[1], Lin Kang[1], Weiwei Xu[1], Jian Chen[1], Masoyoshi Tonouchi[2] and Peiheng Wu[1]

[1] Research Institute of Superconductor Electronics, School of Electronics Science and Engineering, Nanjing University, Nanjing, China

[2]Institute of Laser Engineering, Osaka University, 2-6 Yamadaoka, Suita, Osaka 565-0871, Japan

* Email:bbjin@nju.edu.cn; Tel.: +86-25-83621280

We demonstrate the nonlinear effect of electromagnetically induced transparency (EIT) at terahertz (THz) made from superconducting niobium nitride (NbN) film.The film used in this experiment with a superconducting transition temperature of 15.4 K is fabricated by RF magnetron sputtering on a 1mm-thick MgO (100) substrate. The thickness of the film is about 50nm. Our previous work has shown that obvious nonlinear effect of the complex conductivity of the film at THz can be induced for such kind of film [1]. The pattern is a planar metamaterial structure mimicking three-level EIT system with a unit cell consisting of a dark and a radiative resonator[2]. The straight metal strip in the right functions as the radiative resonator. It can be viewed as a dipole antenna and has strong coupling with the external radiation. The dark resonator is the double-gap split ring resonator (DSRR). The intense single-cycle THz radiation is generated by optical rectification in a LiNbO3 crystal using titled-pulsed-front excitation, as shown in Fig.2[3]. The experimental setup consisted of a 100-fs Ti:Sapphire regenerative amplifier operating at 800nm with a repetition of 1 KHz and a conventional THz detection system based on the electro-optical sampling technique. The peak value of electric field on the sample is about 30 kV/cm in a cryostat. The transmission is measured by a high-field THz time-domain spectroscopy.   .

Fig.3 shows the obtained transmission spectrum. A typical EIT-like behavior is observed, especially at low incident THz field. An interesting finding is that as the incident THz field grows up to the maximum value of E_0, the transmission peak value of transparency window slightly decreases and the two resonance dips both become much broader, i.e., the transmission peak does not have much change compared with the strong variation of the transmission dips. Obviously this result is quite different from the previous one on the nonlinear superconducting THz metamaterial [1].To understand how the two resonators interact each other in this experiment, we introduce a hybrid coupling model to fit the experimental transmission spectra[4]. The fitting shows that only the ohmic loss of the bright resonator varies with the strength of incident THz field. So, we can say the field dependence of bright and dark modes are quite different from the dark resonator. The incident wave is directly coupled to the bright mode and then transfer to the dark mode via a very small κ. This implies that we can partially control the selective mode or part of metamaterial by the introduction of incident intense THz field, which offer an effective manner to design and actively control the metamaterial, and thus may bring nonlinear metamaterial into novel applications.

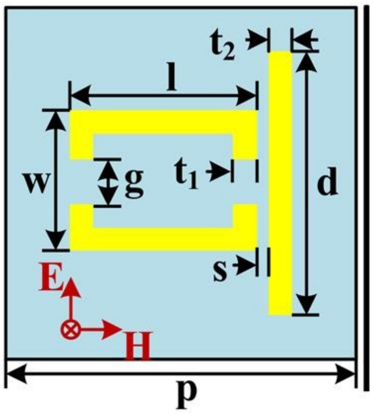

Fig.1 Schematic of the unit cell, which has a period of p=120 μm.The geometrical parameters are: l=64μm, w=48 μm, s=4μm, t1=t2=8μm, g=15μm, d=90μm,respectively.

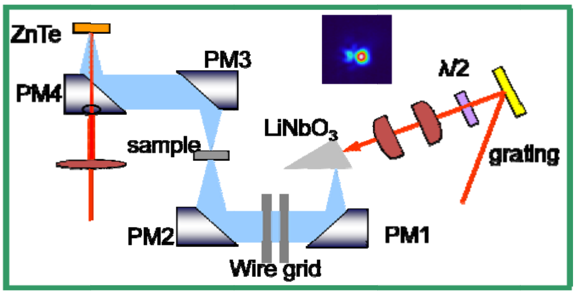

Fig.2Generation of the intense THz field for nonlinear THz TDS measurement

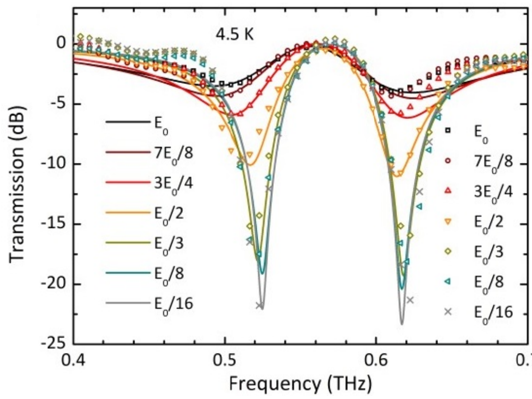

Fig.3 Transmission spectra of the sample under various incident THz fields at 4.5 K. The symbol curves are experimental data and line curves are the fitted transmission.

REFERENCES:

[1] C. Zhang, B. Jin, J. Han, I. Kawayama, H. Murakami, J. Wu, L. Kang, J. Chen, P. Wu and M. Tonouchi, Terahertz nonlinear superconducting metamaterials, Appl. Phys. Lett. **2013**,102, 081121.

[2] J. B. Wu, B. B. Jin, J. Wan, L. J. Liang, Y. G. Zhang, T. Jia, C. H. Cao, L. Kang, W. W. Xu, J. Chen and P. H. Wu, Superconducting terahertz metamaterials mimicking electromagnetically induced transparency, Appl.Phys.Lett. **2011**,99, 161113

[3] H. Hirori, A. Doi, F. Blanchard and K. Tanaka, Single-cycle terahertz pulses with amplitudes exceeding 1 MV/cm generated by optical rectification in $LiNbO_3$, Appl. Phys. Lett. **2011**, 98, 091106

[4] W. Tan, Y. Sun, Z. Wang and H. Chen, Manipulating electromagnetic responses of metal wires at the deep subwavelength scale via both near- and far-field couplings, Appl. Phys. Lett. **2014**,104, 091107