Superconducting Metamaterial: Resonant Response at Visible Wavelengths

Kaveh Delfanazari[1], Vassili Savinov[1], Otto L. Muskens[2] and Nikolay I. Zheludev[1,3],*
[1]Optoelectronics Research Centre and Centre for Photonic Metamaterials, University of Southampton, Southampton, SO17 1BJ, United Kingdom, Tel: +44 (0) 2380593134, Fax: 44 (0) 2380593149,
[2]Physics and Astronomy, University of Southampton, Southampton, SO17 1BJ, United Kingdom,
[3]Centre for Disruptive Photonic Technologies, Nanyang Technological University, 21 Nanyang Link, 637371, Singapore,
[*]E-mail:kd2n12@orc.soton.ac.uk, web: www.nanophotonics.org.uk/niz

Abstract: The resonant electromagnetic response of niobium metamaterial show strong temperature variation near the critical temperature in the visible wavelengths, i.e. above the superconducting bandgap. Plasmonic mechanism of the optical response is discussed.

The low loss and unique electromagnetic properties of superconductors present an opportunity for achieving metamaterials with extreme nonlinearity and tunability. To date all demonstration of these superconducting metamaterials have been reported in microwave, millimetre wave and THz wave regime. The response of such metamaterials has been tuned with incident light, magnetic fields, electrical current and temperature.

Here we report for the first time the response of a tunable superconducting metamaterial operating at visible wavelengths. The metamaterial sample was fabricated by depositing a 300 nm niobium (Nb) film (transition temperature of 9.2 K) on a sapphire substrate (0.5 mm thick). An array of slits (each with length L=350 nm and width w=100nm) covering a total area of 100 μm × 100 μm milled by using a focused ion (FIB) beam to the Nb film. Our metamaterial sample was then placed inside the closed-cycle optical cryostat that provides temperature control range of 4-300 K. The experimental setup is depicted schematically in Fig. 1(a). The scanning electron microscope (SEM) image of the nano-slit is shown in Fig. 1(b). In this study, incident light is polarized in the y direction as defined in Fig. 1(b). Optical spectra were collected as a function of temperature using this optical cryostat. Light from a broadband supercontinuum source was focused to an approximately 50 μm diameter spot onto the metamaerial.

Absorption spectrums of the metamaterial at temperatures above and below superconductor transition temperature (T_c≅9.2 K) as a function of wavelength (450-1050 nm range) are shown in Fig. 1(c). We used relatively low (100 μW) illumination intensities which are estimated not to affect the superconducting state. Our metamaterial shows temperature dependent resonance strength and spectral features (see wavelengths 651 and 783 nm in Fig. 1(c)). The strongest resonance is occurred at temperature 4.5 K far below Nb film T_c as represented by sharp dip at 651 nm and peak at 783 nm. As the temperature increases both resonances shrink and gradually broadening. The dip in adsorption spectrum at 651 nm vanishes completely when temperature goes above T_c. In the presentation we will discuss this physics and show that experimental observations are in good agreement with the simulation results performed by 3D Maxwell equation solver COMSOL modelling package.

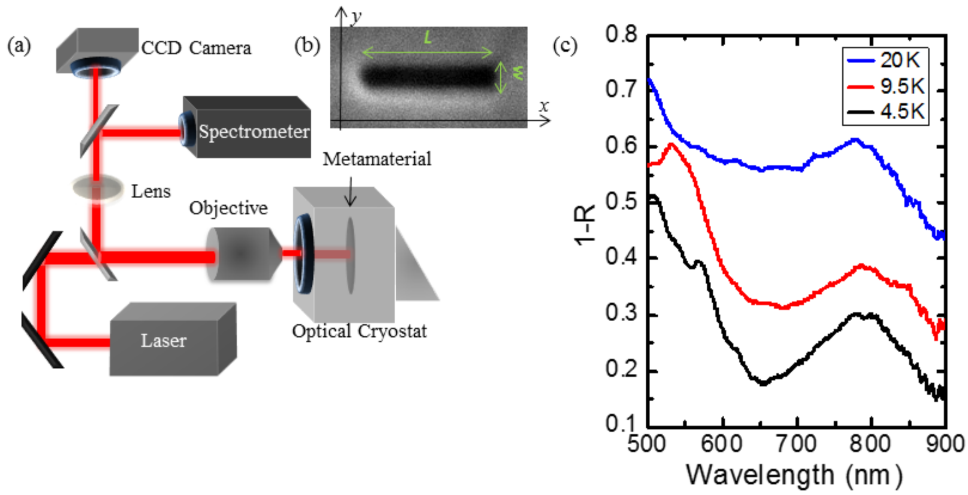

Figure 1. (a) **Probing superconducting metamaterial at optical frequencies.** Metamaterial is placed inside the closed-cycle optical cryostat under ultrafast optical excitation. (b) SEM image of the nano-slit of the metamaterial array (meta-atom). (c) Absorption spectra, 1-R, of nano-slit array for y-polarized light (graphs are vertically shifted for presentation purpose).