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Optical Superconducting Plasmonic Metamaterial

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***Abstract* – We report on the discovery of a new type of optical plasmonic media: by observing absorption lines in a superconducting metamaterial out of Nb, we find that the Nb metamaterial shows plasmonic properties at visible wavelengths. This suggests that superconductors are a feasible platform for new generation of plasmonic metadevices.**

I. INTRODUCTION

Superconductors with strongly tunable superfluid plasma frequency, zero dc and low transient frequency resistances are truly plasmonic materials. Their unique electromagnetic response governed by Cooper pairs is strongly affected by external perturbations such as magnetic fields, current, temperature and light. For these reasons highly tunable superconducting metamaterials are developed in recent years. However, all demonstrations of these metamaterials have been performed in microwave, millimetre and terahertz (THz) wave regime as the common wisdom is that superconductivity cannot be exploited above THz frequencies because of the superconducting energy gap limitation [1-3]. Here we present the first experimental results of a Nb superconducting plasmonic metamaterial operating above the superconducting energy gap- visible wavelengths, and show that extreme sensitivity of superconductivity to external perturbations, e.g. light, can be achieved even at optical frequencies.

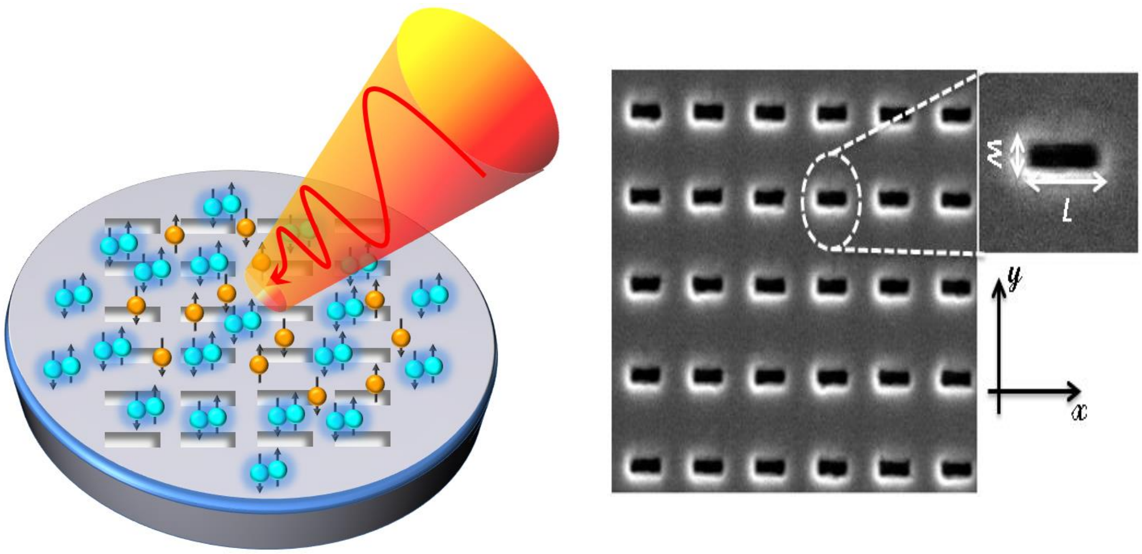

Fig. 1. Superconducting optical metamaterial. (a) artistic impression. The interaction of visible light with nanostructure patterns on the surface of Nb superconducting film breaks a number of cooper pairs (light-blue pairs) and excites the quasiparticles (orange). (b) Scanning Electron Microscope (SEM) image of the Nb nano-slit array metamaterial fabricated by focused ion beam milling on the facet of a 300 nm thick Nb film .

II. FABRICATION AND MEASUREMENT METHOD

Nb superconducting metamaterial was fabricated by depositing a 300 nm thick Nb film with a transition temperature (T_c) of ≅ 9.2 K, on a half millimetre thick sapphire substrate (disk of 30 mm diameter). An array of slits each with length L=350 nm and width w=100 nm covering a total area of 100×100 μm^2 was milled using a focused ion beam (FIB) into the Nb film. Our metamaterial sample was then placed inside an optical cryostat that provides temperature control range of 4-300 K. The high fabrication quality and uniformity of the sample are confirmed by scanning electron microscope image (See Fig. 1). Light with relatively low illumination power polarized perpendicular to the slits (y-axis in Fig 1.(b)) from a broadband ultrafast laser was focused to an approximately 50 μm diameter spot on the metamaterial.

III. EXPERIMENTAL RESULTS

Plasmonic absorption lines of the Nb superconducting metamaterial are shown in Fig. 2 for room temperature (300 K), above (20 K) and below (4.5 K) the superconductor transition temperature. As seen in this figure, data show temperature dependent resonance strength and spectral features. The strongest resonance is observed at a temperature of 4.5 K (red curve) below the Nb T_c as represented by a sharp dip at 651 nm and a peak at 783 nm. With increasing temperature both resonances shrink and gradually broaden. The dip in adsorption spectrum at 651 nm and a small resonance peak appeared around 570 nm vanish completely when temperature goes beyond T_c. The peak at 783 nm is also blue-shifted when temperature is increased.

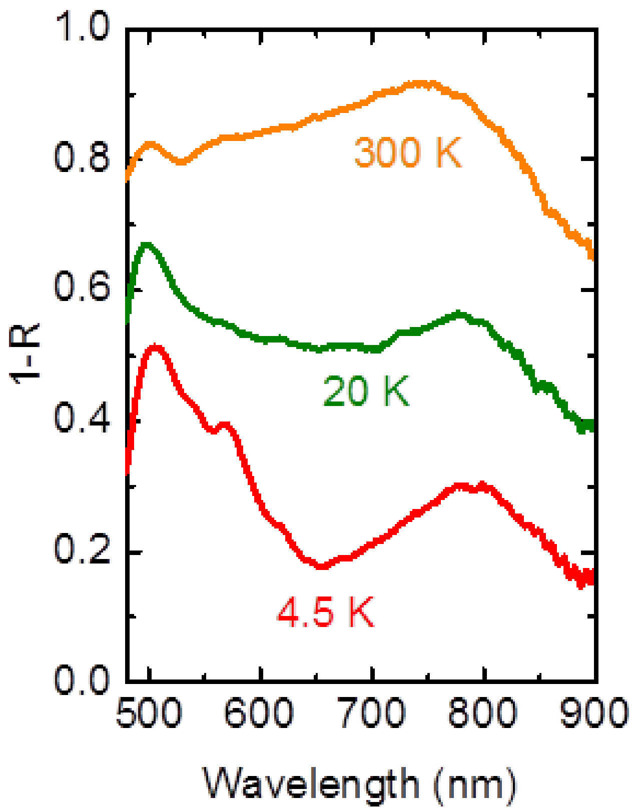

Fig. 2. Absorption spectra, 1-R, of the metamaterial for y-polarized light at a selection of temperatures: room temperature (orange), above (green) and below (red) the superconducting transition temperature (graphs are vertically offset for presentation purpose).

IV. Conclusion

We showed the first experimental observation of plasmonic resonant response in the superconducting metamaterial operating at optical wavelengths, i.e. above the superconducting gap. Our observation strongly suggests the use of superconductors as an alternative to conventional metals such as gold and silver in the metamaterials and plasmonics devices at optical frequencies.

Acknowledgement

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