*12th International Congress on Artificial Materials for Novel Wave Phenomena – Metamaterials 2018*
Espoo, Finland, Aug. 27th – Sept. 1st, 2018

# Coherent Perfect Absorption and Switching in a Fiberized Quantum Network with Plasmonic Metadevice

**A. N. Vetlugin[1], R. Guo[1], A. Xomalis[2], S. Yanıkgönül[1,3], G. Adamo[1], C. Soci[1], N. I. Zheludev[1,2]**

[1] Centre for Disruptive Photonic Technologies, TPI, SPMS, Nanyang Technological University, Singapore 637371, Singapore
[2] Optoelectronics Research Centre & Centre for Photonic Metamaterials, University of Southampton, Southampton SO17 1BJ, UK
[3] Advanced Concepts and Nanotechnology Division, Data Storage Institute, Agency for Science, Technology and Research, 138632, Singapore
a.vetlugin@ntu.edu.sg

***Abstract* – In this report we provide the first demonstration of a fully fiberized quantum network with a fiber-integrated metamaterial as a dissipative switching element. Using the phenomenon of coherent absorption in plasmonic metamaterials we achieve high-contrast control of the single photon absorption probability and demonstrate switching application.**

While the absorption of photons from a travelling wave is probabilistic, standing wave absorption can be observed deterministically [1], with nearly unitary probability of coupling a photon into a mode of the material, for example, a localized plasmon when a metamaterial is excited at the plasmon resonance. This process has been used in various forms of switching applications in free space with CW [2] and short-pulse lasers [3], as soon as with single photon [4], entangled [5] and N00N [6] states. Recently coherent perfect absorption phenomenon was demonstrate in photonic integrated circuit performance [7], and was used to implement classical logical functions XOR, NOT and AND in fiber network with CW laser [8].

Here we demonstrate manipulation of light at a single photon level in an all-fiber-optic quantum network, Fig. 1. The network is interrogated by the heralded single photons, produced via degenerate spontaneous parametric down-conversion in a beta-barium borate crystal, which is pumped with a CW laser at a wavelength of 405 nm.

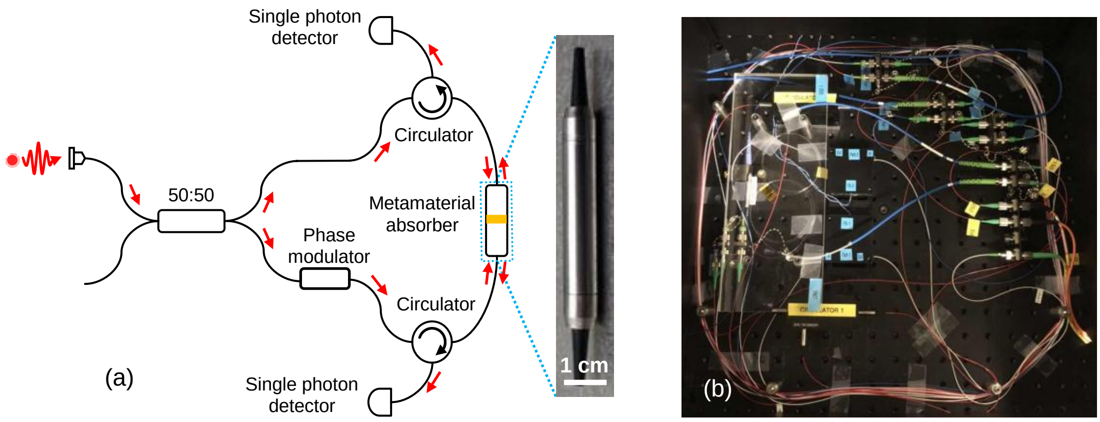


Fig. 1. Fiber-optic quantum network for active single photon switching using a fiberized plasmonic metamaterial absorber (inset shows a picture of the packaged metadevice): (a) schematics; (b) photograph.

Idler photon (not shown) is directed to a single photon avalanche photodiode and heralds the presence of a signal photon, which is launched to a fiberized Sagnac-like interferometer, Fig. 1. Fiber stretcher, placed at the bottom arm of the interferometer, is used as a phase modulator producing phase shift, proportional to applied voltage from a function generator, thus controlling interference of light in the middle of the interferometer, where a fiber-integrated metadevice package (insert on Fig. 1a) is placed. After passing through the metadevice light is directed by circulators to single photon detectors, signals from which are analyzed by a counter IDQuantique ID800.

Metamaterial deposited on the cleaved end face of a polarization-maintaining single-mode fiber is shown on Fig. 2a. The absorber used here is a plasmonic metamaterial consisting of a 50-nm-thick gold film perforated with an array of asymmetrically split ring apertures [8]. Fiber with deposited metamaterial is imported into a glass fiber ferrule, attached with a second bare fiber and fixed in an external metal housing.

We have achieved continuous control of the single photon absorption probability with visibility of 80% (Fig. 2b) by altering phase retardation in bottom arm of the interferometer. Our experiments were performed in two regimes: 1) in a quantum network actively stabilized on with independent laser source; 2) in a free-running network without stabilization by algorithmic post-selection of the data. We also demonstrate single photon switching regime (Fig. 2c) with active phase modulation, showing the ability of driving the quantum network in time-domain between coherent single photon transmission and absorption regimes.

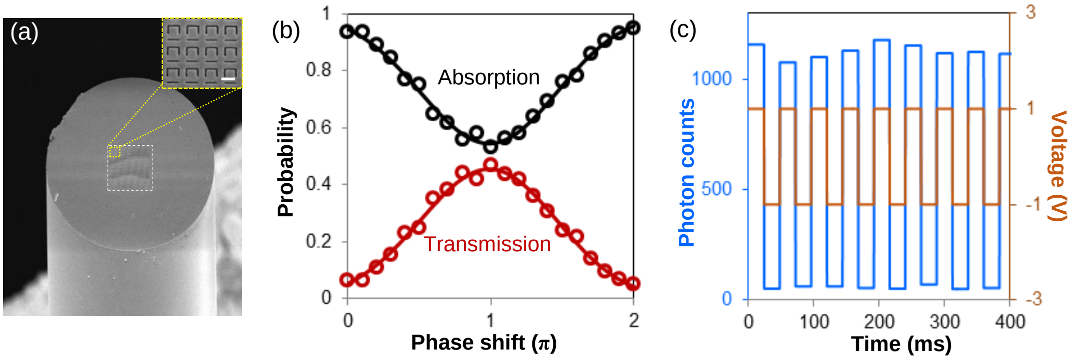


Fig. 2. a) SEM image of the plasmonic metamaterial absorber deposited on the end-facet of the optical fiber (inset shows the SEM image of individual asymmetric split ring resonators, scale bar is 500 nm); b) Single photon absorption and transmission probability by continuous phase shift modulation; c) Demonstration of single photon switching with 20 ms acquisition time: blue line shows the photon counts level, brown line shows the control voltage applied to phase modulator.

Our results demonstrate that stabilized and free-running fiber networks can be robustly used in dissipative single photon switching, thereby presenting powerful opportunities for novel coherent optical data processing architectures and complexity oracles.

## References

[1] Y. D. Chong, L. Ge, H. Cao, and A. D. Stone, "Coherent Perfect Absorbers: Time-Reversed Lasers," *Phys. Rev. Lett.*, vol. 105, p. 053901, 2010.

[2] J. Zhang, K. F. MacDonald and N. I. Zheludev, "Controlling light-with-light without nonlinearity," *Light Sci. Appl.*, vol. 1, p. e18, 2012.

[3] X. Fang, M. L. Tseng, J.-Y. Ou, K. F. MacDonald, D. P. Tsai, and N. I. Zheludev, "Ultrafast all-optical switching via coherent modulation of metamaterial absorption," *Appl. Phys. Lett.*, vol. 104, p. 141102, 2014.

[4] T. Roger, S. Vezzoli, E. Bolduc, J. Valente, J. J.F. Heitz, J. Jeffers, C. Soci, J. Leach, C. Couteau, N. I. Zheludev and D. Faccio, "Coherent perfect absorption in deeply subwavelength films in the single-photon regime," *Nat. Comm.*, vol. 6, p. 7031, 2015.

[5] C. Altuzarra, S. Vezzoli, J. Valente, W. Gao, C. Soci, D. Faccio, and C. Couteau, "Coherent Perfect Absorption in Metamaterials with Entangled Photons," *ACS Photonics*, vol. 4 (9), p. 2124, 2017.

[6] T. Roger, S. Restuccia, A. Lyons, D. Giovannini, J. Romero, J. Jeffers, M. Padgett, and D. Faccio, "Coherent absorption of N00N states," *Phys. Rev. Lett.*, vol. 117, p. 023601, 2016.

[7] B. Chen, R. Bruck, D. Traviss, A.Z. Khokhar, S. Reynolds, and D.J. Thomson, "Hybrid Photon−Plasmon Coupling and Ultrafast Control of Nanoantennas on a Silicon Photonic Chip," *Nano Lett.*, vol. 18, p. 610, 2018

[8] R. Bruck, B. Mills, B. Troia, D. J. Thomson, F. Y. Gardes, Y. Hu, G. Z. Mashanovich, V. M. N. Passaro, G. T. Reed, and O. L. Muskens, "Device-level characterization of the flow of light in integrated photonic circuits using ultrafast photomodulation spectroscopy," Nat. Photonics, vol. 9, p. 54-60, 2015

[9] A. Xomalis, I. Demirtzioglou, E. Plum, Y. Jung, V. Nalla, C. Lacava, K. F. MacDonald, P. Petropoulos, D. J. Richardson, and N. I. Zheludev, "Fibre-optic metadevice for all-optical signal modulation based on coherent absorption," *Nat. Comm.*, vol. 9, p. 182, 2018.