Fibre-optic metadevice for all-optical coherent signal processing at 40 Gbit/s

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***Abstract*—We demonstrate a fully functional metadevice performing coherent all-optical logical operations including NOT, AND and XOR at up to 40 Gbit/s at wavelengths between 1530 nm and 1565 nm and demonstrate that the underlying mechanism has a bandwidth of 100 THz.**

Keywords—metamaterial; metadevice; coherent absorption; coherent transparency; signal processing

I. INTRODUCTION

We provide the first demonstration of a high-bandwidth, low-intensity fiberized all-optical gate exploiting coherent absorption in a plasmonic metamaterial film. The fully packaged fiberized version of the switch has been tested at bitrates of up to 40 Gbit/s while free-space versions of the gate have been shown to provide 100 THz bandwidth and to operate at arbitrarily low intensities. Our work illustrates how major bandwidth and energy challenges of optical telecommunications and information processing networks can be tackled by merging metamaterials and optical fibre technologies.

II. RESULTS

The metadevice exploits that strong light-matter interaction can be achieved with engineered metasurfaces that are thin compared to the wavelength. This creates the opportunity to place a metasurface at a node or anti-node of the standing wave formed by counter-propagating coherent optical signals (Fig. 1), corresponding to negligible and enhanced light-matter interaction, respectively, e.g. 0% absorption and 100% absorption [1]. This approach does not rely on nonlinear materials and therefore it can offer high optical contrast in combination with up to 100 THz bandwidth (plasmon lifetime) and arbitrarily low intensities down to the quantum regime. Nevertheless, it allows one optical pulse to be switched off by another and other essentially nonlinear functionalities enabling applications from all-optical amplification to all-optical logic gates. The device principle was tested successfully with 6 fs optical pulses as well as single photons.

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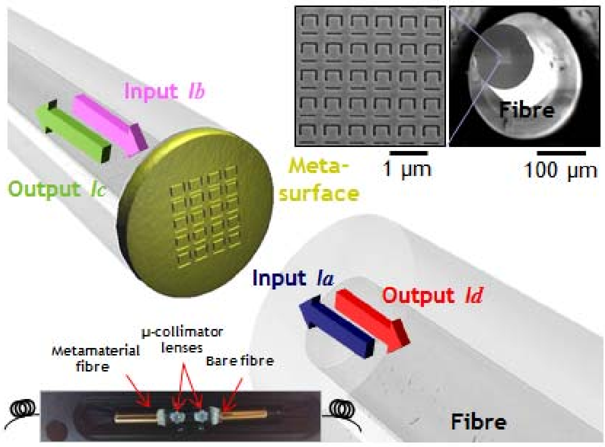

Fig. 1. Schematic of the data processing metadevice based on coherent interaction of input light beams Ia and Ib on a plasmonic metamaterial absorber of 70 nm thickness (gold) fabricated on the end face of a telecoms fibre. Insets show scanning electron micrographs of the nanostructured fibre end and a photo of the assembled metadevice.

Our fully packaged fiberized metadevice is based on a plasmonic metamaterial fabricated on the end face of a polarization-maintaining single-mode telecommunications fibre (Fig. 1). The plasmonic nanostructure of 70 nm thickness acts as switchable absorber, allowing the absorption of one optical pulse to be controlled by another coherent optical pulse. We demonstrate nonlinear input-output characteristics and all-optical logical data processing functions including NOT, AND and XOR at kHz and GHz bitrates in a fibre network assembled from standard telecoms components at wavelengths from 1530 nm to 1565 nm. Fig. 2 illustrates the NOT operation over this wavelength range at 40 Gbit/s. In this case, the inversion of an intensity-modulated signal A that is incident on the metasurface within the metadevice is achieved by illuminating the metasurface with a second counterpropagating coherent optical signal B. The phase of optical signal B is adjusted such that it interferes constructively with signal pulses A on the metasurface, causing coherent perfect absorption of incoming signal pulses and thus their removal from the output signal, i.e. a logical “1” at the input becomes a logical “0” at the output. When there is no signal pulse A illuminating the metasurface, then signal B contributes to the output signal, causing a logical “0” at the device input to turn into a logical “1” at the output. In this way, coherent perfect absorption of light with light results in inversion of the input signal. Similarly, coherent perfect transparency due to destructive interference of light on the metasurface and coherent perfect absorption due to constructive interference on the metasurface can also be exploited to realize logical XOR and AND operations and we will demonstrate this at kHz and GHz bitrates.

In order to assess the ultimate bandwidth of all-optical logical functions based on coherent perfect absorption, we measured coherent perfect absorption with femtosecond laser pulses on a freestanding metasurface that is similar to the structure employed in the metadevice, see Fig. 3. The measurements show that pulses as short as 11 femtoseconds can still be efficiently absorbed and even for 6 fs laser pulses coherent absorption still reaches about 75%, indicating a potential bandwidth of about 100 THz.

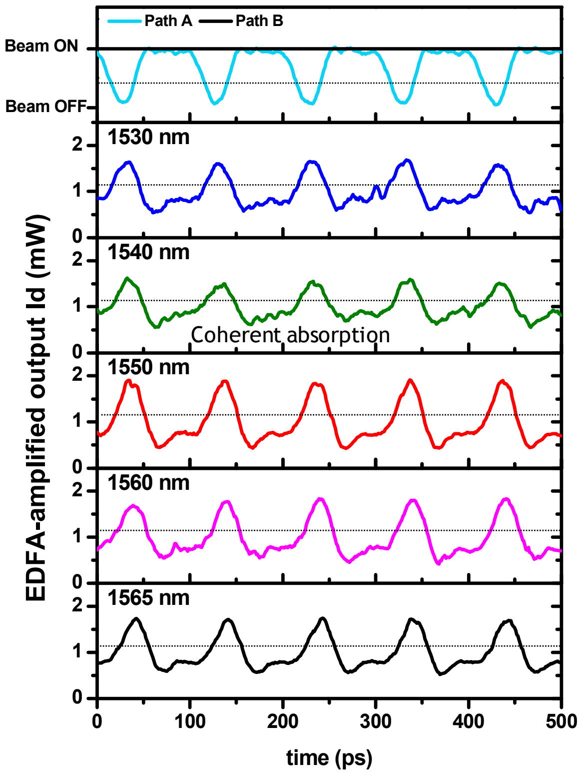

Fig. 2. Broadband inversion NOT A of a 40 Gbit/s signal A at wavelengths from 1530 nm to 1565 nm. The signal corresponds to an intensity-modulated bit pattern 1011 repeating at 10 GHz (top) and the inverted output signal was measured at different wavelengths (bottom). Beam B has a constant intensity and causes coherent absorption of incoming signal pulses. The logical states “1” and “0” are separated by a horizontal dotted line on each graph.

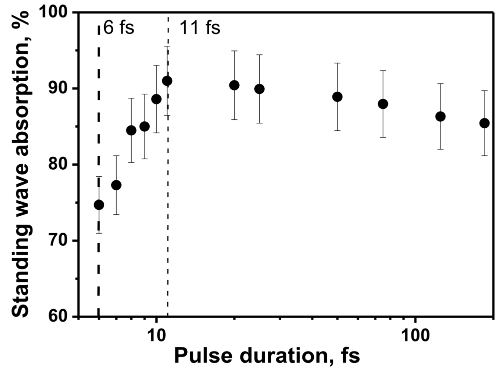

Fig. 3. Interaction of femtosecond pulses with a thin absorber. Coherent absorption of counterpropagating femtosecond pulses measured on a freestanding plasmonic metamaterial for different pulse durations at 800 nm wavelength.

III. Summary

In summary, we report a first working prototype of a data processing metadevice that is compatible with existing optical telecommunications technology. We anticipate that such metadevices can provide solutions for low-energy all-optical information processing at up to 100 THz as well as quantum information networks.

References

[1] J. Zhang, K. F. MacDonald, and N. I. Zheludev, “Controlling light-with-light without nonlinearity,” Light: Science and Applications, vol. 1, e18, 2012.