Coherent cryptography with dissipative all-optical metamaterial gates

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Abstract: We demonstrate a new type of secure optical communication based on dissipative metamaterial logic gates that encrypt and decrypt information in an all-optical telecommunication fibre network with mutually coherent signal channels.

Optical layer security protects data as it is transmitted through fibre-optic networks. Here, we propose and demonstrate a secure communication protocol for coherent information networks, where signal and key distribution lines are mutually coherent. In such networks, the phase difference between different information channels carries information that can be exploited for cryptography.

Coherent interaction of light with light on a thin absorber allows one optical signal to control absorption of another, from coherent perfect transmission to coherent perfect absorption. This allows the implementation of analogue gates for all-optical signal processing, e.g. to perform logical functions and selective elimination of an optical signal component. Say Alice would like to send an encrypted message to Bob (Fig. 1a). By mixing mutually coherent Data and Key signals in a 1st coherent optical gate, Alice generates an encrypted data signal corresponding to Data XOR Key. Then Alice transmits the encrypted signal and the key through separate channels to Bob. An eavesdropper Eve cannot recover the data from one channel alone. Bob uses a 2nd coherent optical gate to eliminate the key from the encrypted signal and recovers the original data.

In our experiments, the coherent optical gates for encryption and decryption are realized as fibre-optic meta-devices containing a plasmonic metasurface absorber of 70 nm thickness that covers the core of a cleaved optical fibre (Fig. 1b). Fig. 1c shows proof-of-principle experiments at a bitrate of 3 Gbit/s at the telecommunications wavelength of 1550 nm. An intensity-modulated data bit pattern (10110001) is encrypted with a key bit pattern (10010110) in the 1st optical gate metadevice, resulting in an encrypted signal Data XOR Key (00100111). The XOR operation results from coherent absorption of simultaneously-arriving data and key pulses that interfere constructively on the metasurface coherent absorber. The encrypted bit pattern is combined with the key in the 2nd optical gate metadevice, causing coherent absorption of the key and thus decryption of the data (10110001).

In summary, we demonstrate a cryptographic scheme for networks with mutually coherent information channels. Our approach is applicable to any wave information carrier and we will discuss several modes of encryption, including a solution that offers perfect secrecy.

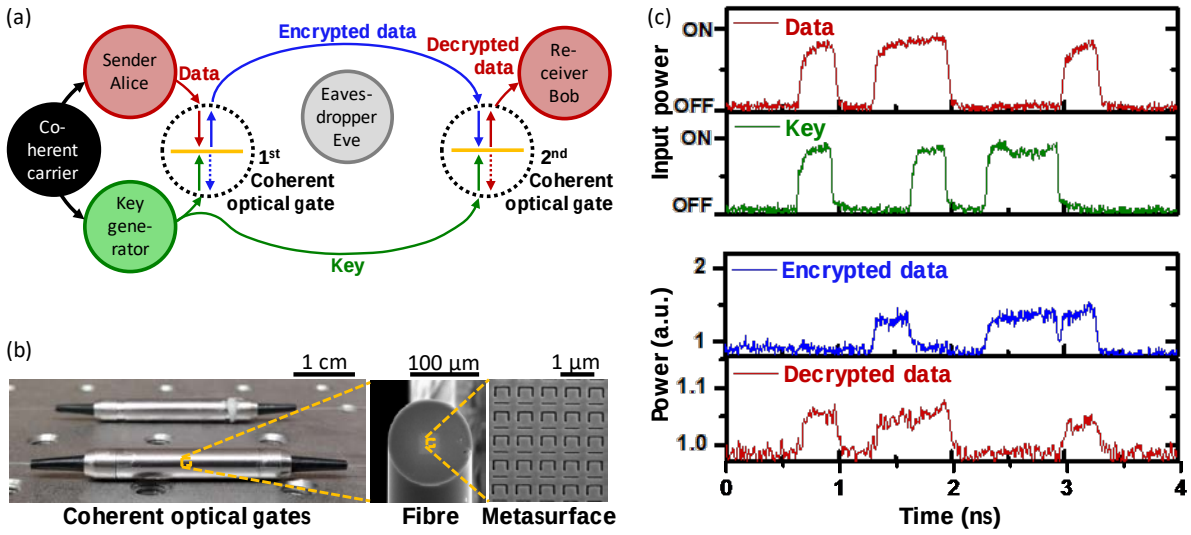

Fig. 1 Coherent cryptography. (a) Alice encrypts her message through interaction of mutually coherent data and key signals on the 1st coherent optical gate. Bob decrypts the secret message through interaction of encrypted data and key on the 2nd coherent optical gate. (b) Coherent optical gate devices used for encryption and decryption, each containing a plasmonic coherent perfect absorber metasurface on the core of a cleaved optical fibre. (c) Power traces of data, key, encrypted data and decrypted data at a data rate of 3 Gbit/s.