# Bistable Spiking Circuit with Graphene Excitable Laser for Cascadable Photonic Logic

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**Abstract:** We demonstrate a photonic bistable spiking circuit with a graphene excitable laser for cascadable logic. This technology could be a potential candidate for applications in novel all-optical devices for information processing and computing.

Photonic neuromorphic processing exploits the biophysics of neuronal computation algorithms [1] to provide a wide range of computing and signal processing applications by harnessing the high speed, high bandwidth, and low crosstalk available to photonic interconnects. This could potentially grant the capacity for complex, ultrafast categorization and decision-making [2]. Neuromorphic signal processing incorporates a sparse coding scheme called spiking. This hybrid analog and digital processing technique takes advantage of both the bandwidth efficiency of analog computation and the noise robustness of digital computation [3], making it attractive to information processing. We recently discovered [4][5] a close analogy between the dynamics of lasers and those of biological neurons, both of which can exhibit excitability [6]—systems that can be excited from their in a stable steady rest state to emit a spike by a super-threshold followed by a refractory period.

Graphene, a 2D atomic-scale hexagonal crystal lattice of carbon atoms [7], has been shown to be an excellent candidate in excitable laser processing devices [8-10]: (1) the linear dispersion near the Fermi energy leads to wavelength-independent absorption of normal incident light; and (2) its large third-order nonlinearity $\chi^{(3)}$ is responsible for nonlinear saturable absorption as a consequence of Pauli blocking which includes ultrafast carrier relaxation, low saturable absorption threshold, and large modulation depth. We experimentally demonstrated an excitable fiber laser incorporating a graphene saturable absorber (SA) for a variety of complex operations including pulse regeneration and reshaping, asynchronous phase locking, and interspike time encoding [9]. Ongoing research on graphene microfabrication [7] may make it a standard technology accessible in integrated laser platforms and could be an enabler for applications of optical computing [11-13]. However, any form of computing requires the following challenges to be overcome: logic-level restoration, fanout/input-output isolation, and cascadability [13].

We experimentally provide a proof-of-concept of cascadability for excitable processors by demonstrating a bistability circuit with a graphene excitable laser and photodetector (PD) in an optoelectronic feedback loop. A recurrent dynamical network such as an attractor network which evolves toward a stable pattern over time has been used in computational neuroscience and plays an important role in neuronal processes such as the formation of memory in processing systems. Fig. 1 illustrates an excitable laser whose output is fed back to the input. Our system is recursive rather than feedforward, possessing a network path that contains a closed loop allowing the system to exhibit hysteresis—essentially an extension of an autapse, a spike processing element feeding back to itself. The excitable laser cavity [8] consists of a chemically synthesized graphene-SA sandwiched between two fiber connectors with a fiber adapter and a 75-cm long highly