Spike Coded Bit Sequence Generation Using Photonic Excitable Laser

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Abstract: Excitable laser dynamics is proposed to realize spike coded bit sequence generation. Numerical simulation based on integrated two-section excitable laser and experimental investigation using graphene excitable fiber laser are both demonstrated.

1. Introduction

Neuromorphic photonic system has been recently discovered to exhibit a strong analogy with its biological counterpart in terms of their underlying excitability mechanisms [1]. This close correlation was first experimentally demonstrated with an excitable fiber laser used in conjunction with graphene as a saturable absorber (SA) [2]. Excitable laser provides a unified platform for optical information processing, especially for photonic spike processing [3]. Spike codes, being digital in amplitude but analog in time, represent a hybrid coding scheme combining both the expressiveness and efficiency of analog processing and the robustness of digital computation. As the foundation of complex spike processing functions, the generation of bit sequence represented by spikes needs a neat and simple solution in the optical domain. This problem is analogous to traditional data format conversion from non-return-to-zero (NRZ) to return-to-zero (RZ), with the difference that this spike coded bit sequence generation should be able to not only interface communication networks employing different data formats, but also interconnect digital computing units or silicon photonic components.

In this paper, we report for the first time all-optical spike coded bit sequence generation using a single photonic excitable laser. Our approach presents reliable generation performance at high bit rate and without clock synchronization. Numerical simulation based on an integrated two-section excitable laser is demonstrated to reach a generation rate as high as 10 Gb/s. Proof-of-principle experiment using a graphene excitable fiber laser also corroborates the feasibility of our approach.

2. Numerical simulation

Our generation scheme draws inspiration from spike processing functions of a graphene excitable laser [3] and maps optical inputs using simple on-off keying (OOK) modulation to bit sequence consisting of spike outputs. Three main properties of excitable laser are exploited here: (1) its excitability threshold ensures the energy for one incoming bit 1 happens to trigger one output spike; (2) its refractory period guarantees the output spikes are interspaced within each bit interval; (3) its temporal integration ability converts the continuous OOK signal to discrete spikes. We construct the simulation model based on the equivalent laser neuron circuit proposed in [4]. Using realistic parameters for distributed feedback saturable absorber (DFB-SA) excitable laser, we simulate our integrated two-section excitable laser with the HSPICE circuit simulator provided by Synopsys.

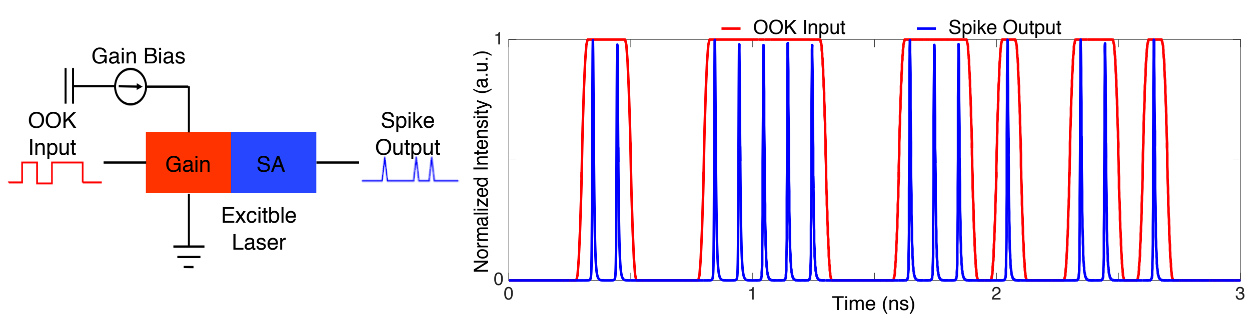

Fig. 1: (a) Simulation model of spike coded bit sequence generation using integrated two-section excitable laser. (b) Simulation waveforms of OOK input and corresponding spike output.

As shown in Fig. 1(a), the excitable laser inputs OOK signal at the edge of the gain section and outputs spike sequence at the edge of the SA section. The gain medium is biased under current $I_{bias} = 16.3\ mA$. The OOK input takes pseudo-random bit sequence (PRBS) of length $2^{10}-1$ with bit period $T_{bit} = 100\ ps$. The rising and falling time (the time it takes for the signal intensity to increase from 10% to 90% of its peak value and vice versa) is set to be around $T_{rise,fall} = 38\ ps$. There are overall 30 bits within the 3 ns clip shown in Fig. 1(b). Apparently, excitable laser relies on no clock signal for synchronization purpose. An excitatory spike is spontaneously triggered whenever the accumulated input OOK signal energy goes beyond the excitability threshold. The spike output can match perfectly bit by bit with its OOK input counterpart by tuning the OOK input power (amplitude for bit 1 is $A = 20\ mA$) and the refractory period (measured to be $T_{ref} = 100.32\ ps$), suggesting the spike bit generation rate is 10 Gb/s.

3. Experimental demonstration

We further investigate the feasibility of using excitable laser dynamics to accomplish spike coded bit sequence generation in a real communication channel. Fig. 2(a) shows the experimental setup of the graphene excitable fiber laser. The whole fiber ring cavity consists of a 75-cm long gain medium of highly-doped erbium-doped fiber (EDF) and a chemically synthesized graphene saturable absorber (SA) sandwiched between two fiber connectors. The gain and SA sections are separated by an isolator (ISO) to ensure unidirectional propagation and a polarization controller (PC) to enhance output pulse stability. The EDF is pumped by a 980/1550 nm wavelength division multiplexer, while the input OOK PRBS of length $2^{10}-1$ is guided to EDF using a 1480/1550 nm wavelength division multiplexer. The output spike signal is decoupled out of the system through the 20% port of the 20/80 coupler. There is no clock signal to synchronize output spikes with input OOK signal.

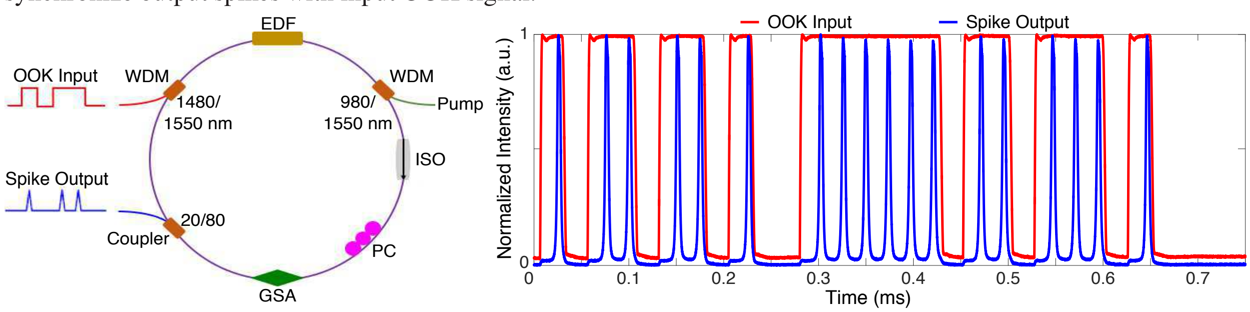

Fig. 2: (a) Experimental setup of graphene excitable fiber laser for spike coded bit sequence generation. (b) Experimental waveforms of OOK input and corresponding spike output.

We present a 30-bit clip in Fig. 2(b) where the bit period is set to be 25 μs. Therefore we have a limited bit rate of 40 kb/s in this experiment and the reason can be attributed to the fact that the volumes of the gain and SA regions are much larger than their integrated two-section excitable laser counterparts. In addition, the spike output confirms that the refractory period of this graphene excitable fiber laser is also around 25 μs, under which circumstance the bit period and the refractory period have close values and leads to a good matching of the OOK input with spike output.

4. Conclusion

We demonstrated high performance all-optical spike coded bit sequence generation using photonic excitable laser without clock synchronization. The numerical simulation based on the integrated two-section excitable laser exhibits the capability of generating spikes at the rate of 10 Gb/s, and the experimental investigation of graphene excitable fiber laser proves the feasibility of our approach in realistic communication system. This technology has potential applications in future optical networks and signal processing.

References

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