Photorefractive soliton synapsis for Surface-Plasmon-Polariton circuits

Tari Hamed,[1] Bile Alessandro,[1] Iodice Mario[2], Fazio Eugenio[1]

[1] Department of Basic and Applied Science for Engineering, Sapienza University of Rome, Italy

[2]Institute of Applied Sciences and Intelligent Systems, National Research Council, Naples, Italy

Introduction

By exploiting the typical functional geometries of the nervous system, information can be stored and processed in the same physical location, unifying memory and processor. This last aspect requires the use of modifiable plastic materials that are capable of assuming different behaviors depending on the information to be stored. Up to our knowledge, most of the platforms that have been introduced as photonic or electronic neural networks, are fixed structures that rigidly perform the calculation without the capability of changing the interconnections as requested[1]. In these structures, the configuration of the neurons and their interconnections are written and predefined. So they are only capable of doing certain limited functions, whereas the biological neurons can dynamically modify the interconnections in the process of training. They can establish new interconnections or if requires they can diminish or strengthen the weight of specific interconnections in synaptic points. This behavior is called the plasticity of the biological neurons which makes them distinguished from the most photonic and electronic neural networks that are demonstrated in the literature[2]. Also, these interconnections have a specific lifetime and their weight's strength is dependent on the extent of their exploitation. In another word, the interconnection's existence and strength is a self-driven process in which the signal itself can reconfigure its pathway by its occurrence redundancy.

Inspired by the biological neurons, we have successfully demonstrated this plasticity feature with a fully optical system[3]. However, to have a link between the electronic counterpart and also increase the number density of the neurons in the network, we have introduced a new hybrid structure that benefits the advantages of both of them simultaneously. Here the hybrid Plasmonic-Solitonic neuron takes into account both the high bandwidth and high speed of the photonic technology and also the smaller wavelength and higher interaction of electrons with the electronic platforms. However, since the Plasmonic systems have an intrinsically higher loss due to the joule effects, so their long-range propagation also is a challenging issue. Fortunately, this hybrid platform provides the long-range and low-loss propagation of the Surface Plasmon Polariton (SPP) signal via coupling it to the soliton interconnections. As a result, long-range propagation of the SPP signal is possible with negligible losses in the range of 0.04-0.07 dB/cm[4] by coupling it to the soliton.

In this study, we have demonstrated the time evolution of the soliton formation through the diffraction profile of the SPP signals via the self-focusing process in the SBN crystal. The donors (Ce^{3+}) introduced as dopants in the SBN crystal, will be transformed into the acceptors (Ce^{4+}) by absorption of the SPP diffracted light (λ=532 nm) at the end of the strip. As indicated in Fig.1A, the electrons are drifted from the beam location to the top surface of the crystal which is the ITO electrode (anode) deposited. It should be noted that the ionized donors will induce an electric field in the opposite direction of the bias applied field and as a result, the refractive index of the photorefractive material at beam location will increase with respect to the dark area through Eq.1.

$$n = n_e - \frac{1}{2} n_e^3 r_{33} \left(\overrightarrow{E_b} + \frac{\vec{D}_{sc}}{\varepsilon_{PR}}\right) \frac{1}{1+\frac{I}{I_{sat}}} \qquad \text{Eq.(1)}$$

This phenomenon gradually forms a solitonic channel and provides the long-range low loss propagation of the SPP signals which is represented through the power profile of the SPP in the frequency domain in Fig.1B. The saturation behavior of the refractive index provides the possibility to realize a sigmoid-type activation function utilizable as a decision-making element in the synaptic points. Since the formation of the solitonic channel requires successive iterations of the signal through the specific channel(represented as the inset plot in Fig.1C), hence, every signal propagation history will be memorized as a refractive index modulation in the photorefractive material and after a while, the further enhancement of the refractive index will be saturated and reaches a plateau. Considering this phenomenon, the processing in the memory will be possible with the aid of solitonic channel formation by counterbalancing effect of the diffraction and self-focusing processes.

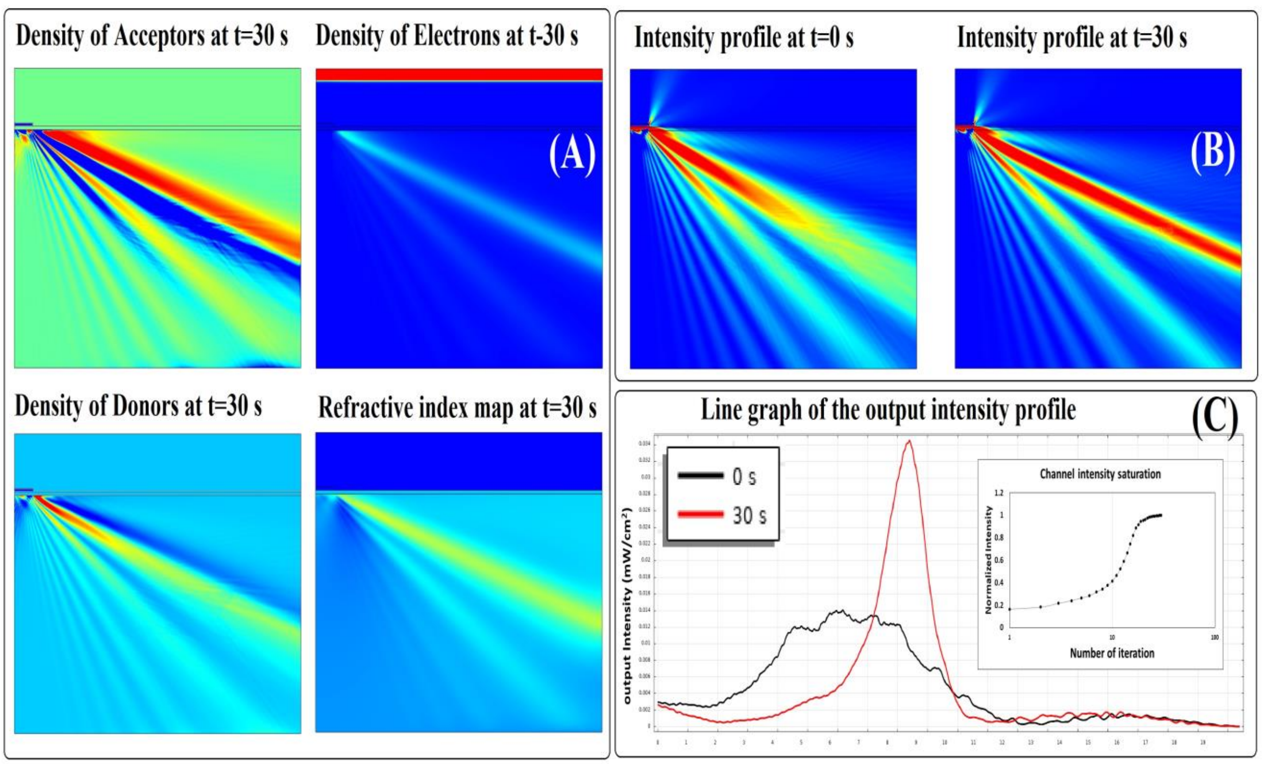

Fig.1, (A) Donors, acceptors, and electrons density at time t=30 sec along with the refractive index profile, (B) Intensity profile of the diffracted light of the SPP before and after the generation of the soliton at t=30 s, (C) Line graph of the intensity profile at the output interface of the SBN crystal at t=0 and t=30 sec after the solitonic channel formation, inset plot indicates the saturation behavior of the solitonic channel formation which follows a sigmoid shape logistic function

References

[1] Zarei, S., M.-r. Marzban, and A. Khavasi, Optics Express, 2020. **28**(24): p. 36668-36684.
[2] Song, Z.W., et al., Optics express, 2020. 28(2): p. 1561-1573.
[3] Bile, A., et al., Neural Computing and Applications, 2021: p. 1-9.
[4] Fazio, E., et al., Rom. Rep. Phys, 2013. 65(3): p. 878-901