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▶ To cite this version:

Anatole Lupu, Vladimir Konotop, H. Benisty. Switching and dynamic memory applications using nonuniform system of coupled waveguides with local parity-time symmetry. Photonics North 2015, Jun 2015, Ottawa, Canada. 10.1109/PN.2015.7292525 . hal-01714370

HAL Id: hal-01714370

https://hal-iogs.archives-ouvertes.fr/hal-01714370

Submitted on 30 Aug 2022

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Switching and dynamic memory applications using nonuniform system of coupled waveguides with local parity-time symmetry

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***Abstract*— We address the potential of a nonuniform coupled waveguides system with gain and loss featuring a PT-symmetry configuration for the realization of switching and dynamic memory applications based on a non-reciprocal modal behavior. The possibility for a perfect switching operation in such a non-conservative layout combining loss and gain is demonstrated.**

Keywords—optical switching; buffer memory; gain-loss modulation, Parity-Time symmetry; plasmonics, metamaterials.

I. INTRODUCTION

The development of photonics enabled by the advent of nanofabrication technologies during the past decades has triggered the emergence of new types of artificial structures such as photonic crystals, metamaterials, plasmonic structures, and more recently the so-called PT-symmetric devices, referring to Parity-Time symmetry. The characteristic feature of PT-symmetry is that the refractive index profile of the structures is complex-valued due to the presence of alternating gain and loss regions in the system. These particular spatial repartitions can either occur in the direction transverse to the light propagation direction, as in the case of the coupled directional coupler [1] or in the longitudinal direction, as in the case of the PT-symmetric Bragg grating [2]. Apart from fundamental research motivations, the tremendous interest in these artificial systems is strongly driven by the practical functionalities that can be achieved by modulating the values of gain and loss in such structures.

II. PT-SYMMETRY RELATED FUNCTIONALITIES

A disruptive paradigm of the PT-symmetry concept is that combination and modulation of gain and loss can be advantageously used for obtaining additional functionalities, well beyond the simple idea of loss compensation.

A. Gain-loss modulation optical switching

The effective detuning of the propagation constants in a system of PT-symmetric coupled waveguides is first gradually reduced upon increasing the level of combined gain/loss in the system, until they become imaginary above the critical point. The variation of the effective detuning (i.e. the propagation eigenvalue difference) can be advantageously exploited for the implementation of a switching or modulation through the variation of the gain-loss level below the critical point. This avenue would largely mitigate the lack of electro-optical tunability in fiber optics, metamaterials and plasmonics.

Our theoretical findings also predict a remarkable feature, genuinely connected to the PT-symmetry. The gain level required for switching can be reduced by increasing the loss contribution, with a penalty that turns out to be quite affordable on the transmission level. A further reduction of the amplification level could be expected through the additional implementation of the variable gain-loss profile. We demonstrate the possibility for a perfect switching operation in such local PT-symmetric system and provide derivation for the optimal gain-loss profile corresponding to the switching operation requiring the minimal amplification level that produces switching.

B. Buffer memory operation based on spatial non-reciprocity

This functionality, different from non-reciprocity based on the Faraday magneto-optical effect, is based on the non-reciprocity of mode coupling. In the case of a system of PT-symmetric coupled waveguides the transmission differs depending whether light injection is performed in the gain or loss waveguides. This kind of asymmetric operation can be used for the implementation of a buffer memory function. The remarkable feature is that tailoring of gain-loss or coupling profiles brings an additional degree of freedom allowing for example to provide a strong re-amplification of the signal circulating in the buffer memory loop.

Overall, such non-reciprocal PT-symmetric network systems provides an avenue for novel computational/logic architectures with perspectives for potentially groundbreaking applications.

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