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Non-volatile stochastic photonic element with memory based on chalcogenide material

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This paper demonstrates a special stochastic operation mode of a photonic element with a thin GeTe film deposited at a silicon nitride waveguide. As opposed to traditional deterministic switching between stable states, it has been shown that identical pump laser pulses cause a stochastic change in the transmission coefficient. The discovered effect opens up new possibilities for constructing compact and energy-efficient entropy sources and stochastic computing units directly within integrated photonic circuits.

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Stochastic processes underpin modern security technologies and novel computational architectures. The generation of true random numbers is a critical challenge for cryptography, while controlled stochasticity forms the cornerstone of probabilistic computing and the learning mechanisms in neuromorphic systems [1, 2]. Integrating such functionalities into silicon photonics paves the way for compact, high-speed, and energy-efficient coprocessors to address these demands. Phase-change materials (PCMs) are among the most promising platforms for implementing computing and memory functions within photonic integrated circuits. Their significant optical contrast between amorphous and crystalline states enables the creation of optical memory elements and programmable metasurfaces [3]. Germanium telluride (GeTe) is particularly notable for its higher crystallization temperature compared to other PCMs, which translates into greater data retention stability and operability at elevated temperatures [4]. Traditionally, PCM-based devices have been designed to switch predictably between two or more predefined stable states.

This work, however, demonstrates a special stochastic operational mode in a photonic element featuring GeTe thin film deposited on a silicon nitride waveguide [5]. In this regime, each identical laser pump pulse induces a random, non-deterministic change in the optical transmission. The change can be either positive or negative relative to the previous state. From a materials science perspective, this behavior can be attributed to the specific crystallization kinetics of GeTe. This material is characterized by a high rate of heterogeneous crystal growth coupled with stochastic nucleation events throughout its volume, leading to the observed probabilistic switching.

This work presents a unique operational regime in a photonic element based on GeTe thin film integrated onto a silicon nitride waveguide. Unlike traditional deterministic switching between stable states, we demonstrate that identical optical pump pulses induce stochastic, non-volatile changes in the transmission coefficient

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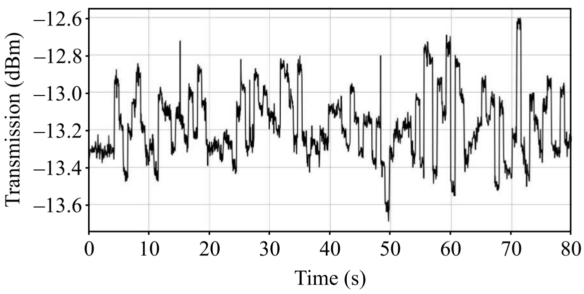

Fig. 1. Dynamics of transmission change of the investigated system

(Fig. 1). The direction of each change (increase or decrease) is random, and the resulting optical state remains stable until the subsequent pulse [6]. Statistical analysis of the transmission evolution reveals three well-defined states with Gaussian distributions. This indicates random switching between film regions possessing different phase compositions and, consequently, distinct optical properties. The results presented here enable the effective harnessing of this pronounced randomness for designing a novel stochastic memory element.

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Conflict of interest. The authors of this work declare that they have no conflicts of interest.

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