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Silicon photonics is rapidly emerging as a viable and robust technology for a large range of applications thanks to its high versatility and to its CMOS-compatibility. Nonetheless, there is a strong interest in achieving monolithic integration of novel materials to provide additional functionalities. In particular, phase-change materials (PCMs) have started to receive considerable attention due to their unique optical and electrical properties. PCMs such as $Ge_2Sb_2Te_5$ (GST) exhibit a large optical index contrast between their amorphous and crystalline phases [1]. Phase transitions in these materials can be initiated by locally increasing the temperature either optically (light absorption) or electrically (Joule heating), with response times potentially below the ns range [1]. These characteristics have already been exploited in multiple applications such as circuit elements for neuromorphic architectures and multi-level optical memories, where PCMs are deposited as thin-film patches over integrated waveguides [2-4].

However, the optical behavior of such devices is non-trivial, and assuming an exponential optical absorption profile as done in [3,4], while computationally efficient, does not accurately model the resulting heat source profile inside the PCM when it is in a crystalline state. Additionally, deducing the absorption from the total optical attenuation does not account for the non-negligible scattering losses of the device, which are explained by the large mismatch between the eigenmodes of the waveguide with and without PCM patch.

We studied the validity of using an exponential profile to model the absorption inside the PCM device by performing 3D Finite-difference time-domain (FDTD) simulations. Here, we show results for the GST-on-SOI platform with the configuration and material properties values described in [4], at $\lambda = 1.55\mu$.

The platform cross-section is schematically represented in Fig. 1(a). The squared amplitude of the electric field from our simulations (see Fig. 1(b)) shows that light is partially scattered away due to mode mismatch. The difference between the absorption profile expected from the total attenuation as done in [3,4] and the results of 3D FDTD simulations is quite important (see Fig. 1(c)). It is essential to correctly model this behavior to properly take into account the granularity of the phase transition along the PCM length. In Fig. 1(d), we show that scattering losses are far from negligible for all practical device lengths. For the 0.3×0.3 μm^2 patch of [4], 12.1% of the input power is radiated away. Thus, looking at the total attenuation at the through port leads to overestimating the overall absorbed power by 26% (our simulation gave an optical attenuation within 0.1 dB of the value reported in [4]).

We have evaluated back-to-back tapered PCM patches to reduce scattering losses. The resulting improvement factor, defined as the ratio of initial to improved scattered power at equal absorption, is shown in Fig. 1(e) for input widths of 50 nm and 150 nm, and a central width of 0.3 μm. The tapered device that gives the same absorption as a 0.3×0.3 μm^2 patch reduces losses by a factor of 1.4, and this improvement increases with the taper length.

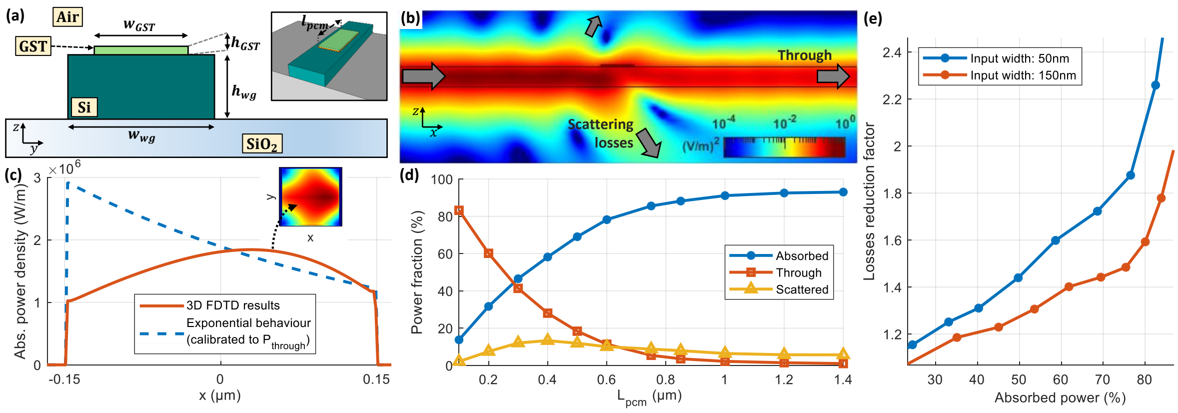

Fig. 1 Results from our analysis; (a) geometry of the device studied ($w_{wg} = 400$nm, $h_{wg} = 180$nm, $w_{GST} = 300$nm, $h_{GST} = 20$nm); (b) squared amplitude of the electric field at the center of the cross-section ($L_{pcm} = 0.3$ μm) and (c) the resulting PCM absorption profile, compared with an exponential model calibrated to the total attenuation of the device (inset: top view); (d) device performance for various patch lengths; (e) scattering losses improvement factor for back-to-back tapered patch designs

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