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Resonant-enhanced optical switch based on non-volatile phase change material GST

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Abstract: We report a resonant-enhanced non-volatile optical switch design based on phase change material $Ge_2Sb_2Te_5$ (GST). Transmission contrast between two GST phase states is significantly improved compared with the non-resonant device.

1. Introduction

Silicon photonic integration has become a development trend for optical systems due to its compatibility with complementary metal-oxide-semiconductor (CMOS) fabrication technology, providing high-speed, low-power, and low-cost solutions. With the dramatic growth of global IP traffic, large-scale silicon photonic integrated circuits (PIC) with high performances are highly demanded. Research on silicon photonic devices has continued for many years and many optical devices have been reported, including switches [1, 2] and modulators [3], etc. However, the weak refractive index (RI) modulation from traditional electro-optic (EO) and thermo-optic (TO) effects in silicon becomes a bottleneck for further scaling down the active devices. High static power consumption in retaining the RI change is another issue that needs to be tackled. Phase change materials (PCMs), such as $Ge_2Sb_2Te_5$ (GST), capable of reversible conversion between amorphous and crystalline states, exhibit a large refractive index contrast and can be a feasible solution to minimize active devices [4, 5]. The non-volatile property of GST also allows the device to be self-holding [6], eliminating static power consumption. It can be used for optical storage applications [7-9]. However, the performance of devices based on PCMs is still restricted by the material characteristics. In optical switch applications, a high extinction ratio (ER) is essential to suppress crosstalk. In optical storage applications, higher ER can give more intermediate states and hence more bits can be stored. Therefore, it is important to improve the ER by device design improvement.

Resonant structures can enhance light-matter interaction and amplify optical absorption in the lossy medium [10]. In this work, we propose a resonance-enhanced non-volatile optical switch by putting GST in a resonant cavity. Light absorption by crystalline GST is significantly enhanced on resonance and hence the on-off ER is greatly increased compared to the non-resonant device.

2. Device structure and principles

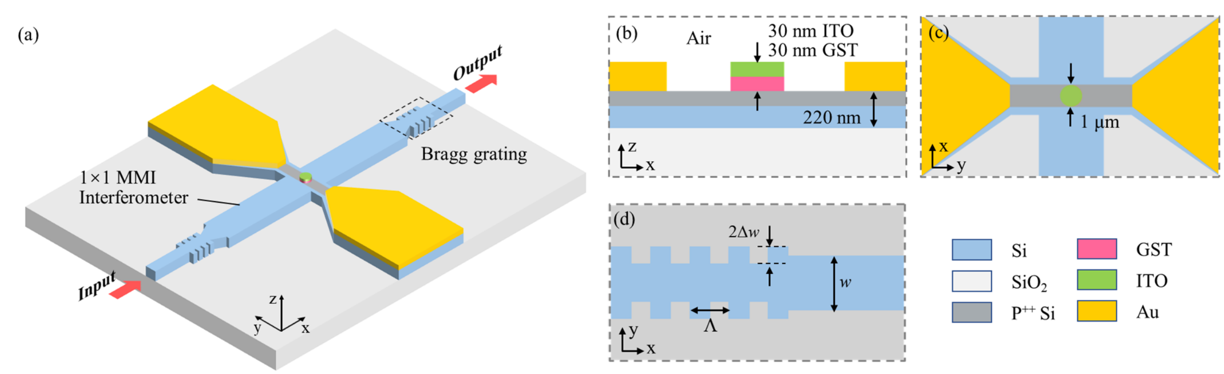

Fig. 1 (a) Three-dimensional view of the switch structure. (b) Cross-sectional view of the active region. (c) Top view of the device active region. (d) Top view of the Bragg grating.

Fig. 1(a) illustrates the schematic structure of the optical switch device, which is composed of a 1×1 multimode interferometer (MMI) inserted in a Fabry-Perot (FP) cavity. The input/output silicon waveguide is 220 nm high and 500 nm wide. The dimension of the MMI is 12.4 μm × 2 μm. Sidewall Bragg gratings form the front and rear mirrors of the FP cavity. In the center of the MMI, a highly-doped silicon strip is crossed to act as a resistive heater. A 30-nm-thick GST is placed on top of the MMI at the crossing center. To protect the GST film, another 30-nm-thick indium-tin-oxide (ITO) film covers the GST on top. The phase change is induced by resistive heating when an electrical pulse is applied. Figs. 1(b) and 2(c) show the cross-sectional view and top view of the active region, respectively. Fig. 1(d) shows the structure of the Bragg grating reflector. The sidewall grating has a duty cycle of f = 50%. When the grating corrugation Δw is 100 nm, the grating period Λ is calculated to be 337 nm using Rytov's formula to satisfy Bragg resonance at the 1550 nm wavelength [11].

3. Simulation results

Figs. 2(a) and 2(b) show the optical power distributions in the non-resonant and resonant-enhanced switches when GST is in the amorphous (am-GST) and crystalline (cr-GST) states, respectively. The grating period is chosen as N = 15. When GST is in the amorphous state, its complex refractive index is 3.983 + 0.0244i. The insertion loss of the device is low and the switch state is "ON". When GST changes to the crystalline state by rapid heating, its complex refractive index increases to 6.485 + 1.054i. The GST then exhibits strong absorption, turning the switch state to "OFF". The FP cavity generates a noticeable resonance in the MMI, enhancing light absorption more significantly in the crystalline state. As a result, the optical transmission contrast between the two GST phase states is largely enhanced.

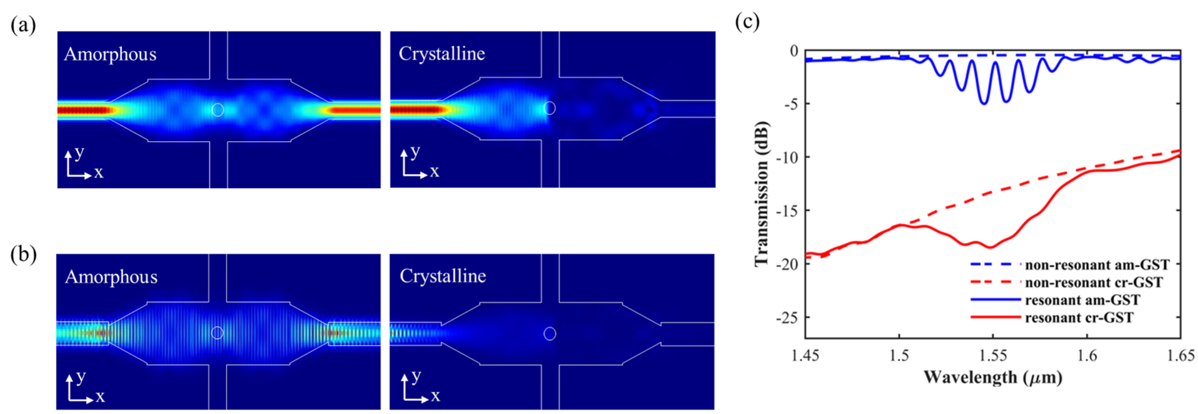

Fig. 2 (a, b) Simulated optical power distributions in (a) the non-resonant switch and (b) the resonant-enhanced switch. (c) Simulated transmission spectra of the non-resonant switch and the resonant-enhanced switch.

Fig. 2(c) shows the transmission spectra of the non-resonant and resonant-enhanced switches at "ON" and "OFF" states. At 1550 nm, the "ON" state loss of the non-resonant switch is 0.5 dB and the "OFF" state loss is 12.8 dB. The ER, defined as the optical power ratio between the am-GST and cr-GST states, is 12.3 dB. The device insertion loss (IL), defined as the loss at the am-GST state, is 0.5 dB. In contrast, prominent resonance peaks can be observed for the resonant-enhanced switch at the "ON" state and one peak is near 1550 nm, which agrees well with the analytical calculations. Due to the higher loss of the crystalline GST, light is fully absorbed by GST in the cavity, leading to reduced transmission in the Bragg resonance window. We choose the wavelength at the resonant peak near 1550 nm as the operation point. The "ON" state loss is 1.1 dB and the "OFF" state loss is 18.3 dB. Therefore, the device on-off ER is improved to 17.2 dB and the IL is slightly increased to 1.1 dB.

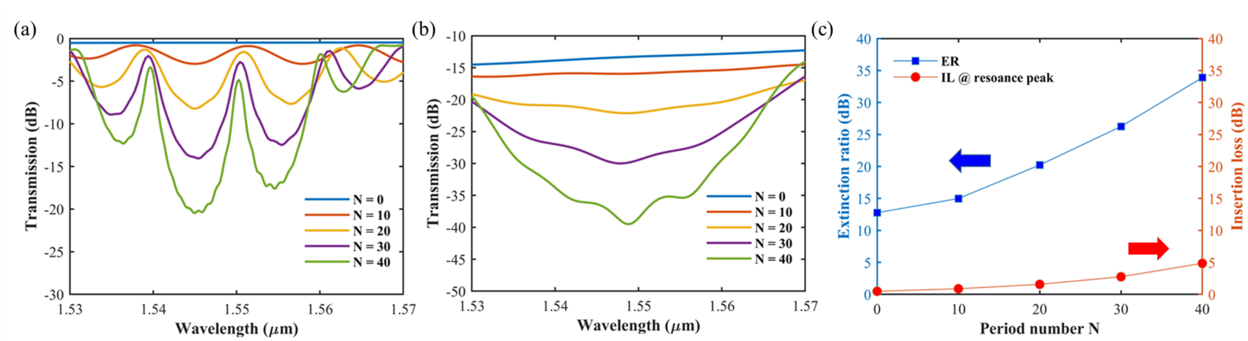

Fig. 3 (a, b) Output spectra of the resonant-enhanced switch with a varying grating period when GST is in the (a) amorphous state and (b) crystalline state. (c) Change of ER and IL with the grating period.

By changing the length of the Bragg grating (L=N×Λ), we can adjust the resonance strength (Q-factor) and hence the output transmission. Figs. 3(a) and 3(b) show the output transmission spectra for am-GST and cr-GST when the grating period (N) varies. Fig. 3(c) shows the ER and IL change with N. When the Bragg reflectors become longer, light absorption by the crystalline GST is further enhanced, and the increment of ER is much more significant than that of IL. For example, the ER exceeds 25 dB and yet the IL is about 2.7 dB when $N = 30$.

4. Conclusion

We have proposed a resonance-enhanced non-volatile optical switch based on the phase change material GST. Through the introduction of the resonant cavity, light absorption is significantly enhanced. When the Bragg grating period number N is 30, the ER increases by more than 10 dB compared with the non-resonant device, while the loss only increases by about 2 dB. This design offers a great improvement in transmission contrast between "ON" and "OFF" states at a small cost. It can satisfy the high ER requirement in optical switching and multi-level optical storage applications.

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