Title

Phase-Change Materials for Group-IV Electro-Optical Switching and Modulation

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Abstract

2 x 2 and 1 x 4 optical routing switches

The electrically actuated optical layer is a thin film of $Ge_2Sb_2Te_5$ or GeTe or GeSe whose thickness is in the 10 to 100-nm range

This film was embedded at the centerline of an SOI, SON, or GeOI channel waveguide structure for *MZI* and *directional-coupler* switching

Alternatively, to switch free-space light beams, **Ge prisms** sandwiching the film were employed.

Highlight

The PCM index is $\mathrm{n_{am} + i\,k_{am}}$ and $\mathrm{n_{cr} + i\,k_{cr}}$ in *am* and *cr*, respectively. Hence the phase change gives **electrorefraction** (ER) of $\Delta\mathrm{n} = \mathrm{n_{cr} - n_{am}}$, and **electro-absorption** (EA) of $\Delta\mathrm{k} = \mathrm{k_{cr} - k_{am}}$. These EA and ER are stronger than those seen in *any prior* EO effect. For an inline, waveguided 1 x 1 modulator device, EA can be optimized to provide deep intensity modulation over a few microns of length. However, for digital modulation, the modulator speed will be limited to ~**10 Mb/s**. Therefore, it is preferable to configure this 1 x 1 modulator as a **low-speed VOA**.

My colleagues and I have investigated $Ge_2Sb_2Te_5$ (GST), GeTe and GeSe PCMs and their index properties are as follows:
GST (1.55 μm) $\mathrm{n_{am} + i\,k_{am} = 4.60 + i\,0.12,\ n_{cr} + i\,k_{cr} = 7.45 + i\,1.49}$;
GeTe (1.55 μm) $\mathrm{n_{am} + i\,k_{am} = 4.22 + i\,0.12,\ n_{cr} + i\,k_{cr} = 6.81 + i\,0.30}$;
GeSe (1.55 μm) $\mathrm{n_{am} + i\,k_{am} = 2.40 + i\,0.00006,\ n_{cr} + i\,k_{cr} = 2.97 + i\,0.00006}$;
GST (2.1 μm) $\mathrm{n_{am} + i\,k_{am} = 4.10 + i\,0.006,\ n_{cr} + i\,kcr = 6.85 + i\,0.50}$.

Clearly, large EA is available for VOAs and SLMs. However, in the switch category, we do not want EA. Low IL and low CT in the 2 x 2 are obtained only when **ER >> EA and $\mathbf{k_{am} < 0.007}$**.

The strategy of minimizing both k_{am} and k_{cr} comes down to a choice of PCM and operation-wavelength. Each PCM has *am* and *cr* bandgap-wavelengths. **For low k's the operation wavelength should be longer than both bandgap wavelengths**.

RESULTS OF SIMULATIONS ON EO SWITCHES

We investigated two 2 x 2 switches: the MZI and the three-waveguide (3W) directional coupler. Here are results at 2100-nm for 10-nm of GST embedded midlevel in 840nm x 420nm cross-section SOI nanowires: the MZI with TM polarization and 38 Pm-length active region gives cross-state IL(0.5dB) with CT (-15dB) and bar-state IL(1.1dB) with CT (-16dB); the 3W with TE polarization and 568 Pm active length in the central waveguide gives second-bar IL(0.8dB) with CT(-16dB) and first-cross IL(1.0dB) with CT(-18dB). Turning to 1550 nm where a 20-nm layer of GeSe was simulated in SOI waveguides of 620nm x 310nm cross-section, we found for the TE polarization that an active length of 19 Pm gave 2 x 2 MZI switching while an interaction length of 115 Pm sufficed for the 3W switch.

In one arm of the MZI, there is end-fire coupling between the PCM-embedded segment and the uniform bulk silicon nanowires at the segment's input and output. These two interfaces lead to an added IL for the MZI which is about 1.2 dB for TE and 0.17 dB for TM in the *cr* state.

Related work

Future work: Looking to the future, it is likely that further k_{cr} reduction at 1.55 would be attained with the PCM $Si_1Sb_2Te_4$ whose $E_g(am) = 0.80$ eV and $E_g(cr) = 0.61$ eV are slightly larger than those of GeSe. Silicon-containing PCMs like $Si_1Sb_2Te_4$ might offer gaps even wider.

References

- Phase-change materials for electro-optical switching in the near- and mid-infrared