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Dispersion controlling in strained silicon waveguides using sub-wavelength grating metamaterials

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We report on controlling of the group velocity dispersion in silicon (Si) strip waveguides, with refractive index engineered sub-wavelength grating (SWG) metamaterials, covered by silicon nitride (Si_3N_4) layer. This waveguide geometry is utilized for breaking the centrosymmetric nature of silicon and opening the route for second-order nonlinearities in the silicon-on-insulator technology. We show by calculations that attractive waveguide dispersion profiles over a broad spectral range can be flexibly tailored by proper control of transversal dimensions and appropriate refractive index engineering. Both normal and anomalous dispersion regimes can be obtained, being one important parameter for various nonlinear applications in photonics.

Waveguide dispersion is an essential characteristic of nanophotonic structures and careful control of this property is of critical importance, playing significant role in development of photonic components using nonlinear processes [1]. Substantial efforts have been put forward in the last years, elaborating various approaches to control the group velocity dispersion, both theoretically and experimentally [2-7]. This particularly includes changing the transversal dimensions [2], utilizing of slot-assisted geometries [3], using conformal dielectric overlayers [4], or adding thin material layers [5,6].

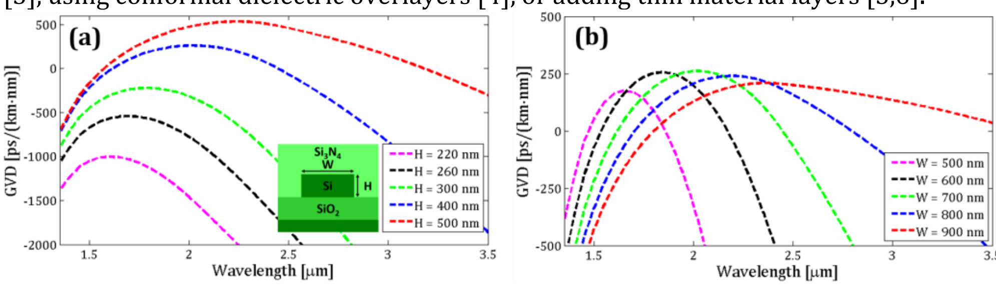

Fig. 1. GVD profiles of strained Si waveguides with different (a) height – H and width of 700 nm, (b) widths – W and height of 400 nm.

Figure 1 shows calculated profiles of the group velocity dispersion in conventional strip Si waveguides, covered by straining Si_3N_4 layer. By changing the cross-sectional dimensions (height x width), it becomes apparent that different dispersion profiles can be obtained and thoroughly engineered. The key ingredient for this is the strong optical confinement, making the geometrical dispersion dominates against the intrinsic material dispersion. In Fig. 1(a) can be seen that the increase of the waveguide height produces a large vertical upshift of dispersion profiles, varying from the normal (~-1000 ps/(km·nm)) to the anomalous (~500 ps/(km·nm)) dispersion behaviors, while keeping the trends in the curve shape. On the other hand, by increasing the waveguide width, as shown in Fig. 1(b), the peak dispersion is shifted towards the longer wavelengths, and the dispersion profiles becomes flatter, i.e. yielding a broader spectral range. This is useful for nonlinear applications demanding phase-matching over a large bandwidths.

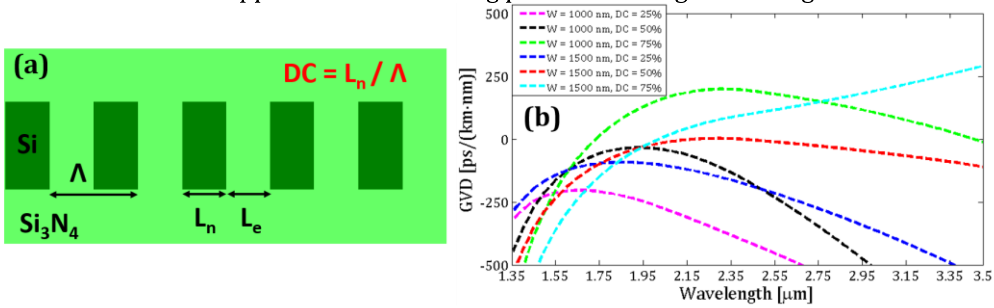

Fig. 2. (a) 2-D schematics of the SWG waveguide. (b) GVD profiles of the strained metamaterial waveguides for different waveguide widths and SWG geometries.

In general, the dispersion engineering in metamaterial waveguides presents a challenge because of the reduced index contrast between the composite waveguide core and the respective claddings, which, in turn, relaxes the mode confinement compared to conventional waveguide arrangements. Here, the local engineering of Si and Si_3N_4 materials, typically used in CMOS foundries, is advantageously exploited to synthesize wide range of optically equivalent metamaterials, with variable properties.

In Fig. 2(b) are shown calculated dispersion profiles as a function of wavelength, for waveguide cross-sections of 500 nm x 1000 nm and 500 nm x 1500 nm, and different longitudinal sub-wavelength grating geometries, i.e. different metamaterial refractive indexes. It becomes apparent that relatively low (up to 200 ps/(km·nm)) and broadband (up to ~1000 nm) dispersion profiles are possible to be tailored by using nano-structuration of Si and Si_3N_4 at sub-wavelength scale. For the same cross-sectional area of the waveguide, the dispersion profiles can be tuned, only by varying the longitudinal waveguide dimensions. This way, multitude of virtually identical waveguides, but with considerable different and variable optical properties (refractive index, mode profiles, and dispersion) can be implemented on the same material platform.

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