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Silicon-on-Insulator Based Nanophotonic Devices for Optical Signal Processing and Nanoparticle Sensing

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Silicon is the material that has become the basic and most important platform for the development of microelectronics in the past few decades. Silicon is not only the dominant semiconductor material for CMOS technology, but also a good candidate for optical high-speed interconnections and signal processing in 1.5-μm telecommunication windows due to its high refractive index, large bandgap and strong nonlinearity. In parallel, silicon-based optical biosensing devices have recently been developed by taking advantage of the optical properties of the nanostructured silicon devices.

Firstly, we studied the nonlinear dispersion in a silicon waveguide using an optical pump-probe setup. The pump and the probe signals are co-propagating in the waveguide, and we observed the nonlinear dispersion (Kerr effect) resulting from cross-phase modulation. The nonlinear dispersion produced polarization rotation in the probe transmission, and therefore all-optical modulation was achieved with less than one picosecond switching window.

Next, we studied the slow-light dispersion in a one-dimensional photonic crystal based microring resonator. We first designed and optimized the waveguide-to-resonator coupling in the high-dispersion regime near the band-edge. Then, we observed the slow-light effect with a maximum measured group index of ~20. Because of the slow-light effect, the free spectral range (FSR) is reduced, and quality factor (Q-factor) is increased in the transmission spectrum. With this approach, we can reduce the size of the ring resonator while maintaining a large FSR. Inspired by the unique standing wave resonance profile patterns, we designed a novel multi-waveguide-coupled microring. Depending on the relative azimuthal position of the waveguides, we can selectively filter a set of resonances for signal processing applications. The bandwidth of the device can be improved by employing a chirped two-dimensional photonic crystal defect waveguide.

Lastly, we designed a novel two-dimensional silicon photonic crystal based air slot microcavities. The slot effect enables tight optical confinement in the 100-nm-wide air slot. Because of this strong optical confinement, this device is highly sensitive to the refractive index perturbation in the air slot region. With an active volume of ~0.08μm^3 and the device is capable of detecting nano-particle with diameters well below 100 nm.