Cavity-Enhanced Photocurrent Generation in a p-i-n Diode Integrated Silicon Microring Resonator Matrix

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Abstract: We report cavity-enhanced photocurrent generation in the 1.55-μm wavelength range in a p-i-n diode integrated silicon microring resonator matrix. We demonstrate photocurrent of ~10 nA at microring resonance wavelengths and cavity enhancement exceeding 11-fold.

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Photocurrent generation in silicon in the 1.55-μm wavelength range is based on nonlinear two-photon absorption (TPA) [1, 2] or linear surface-state absorption (SSA) [3]. SSA is due to the presence of surface defects induced energy levels within the bandgap and is dominant to TPA upon relatively low optical power. Recently, we investigated cavity-enhanced photocurrent generation in the 1.55 μm wavelength range upon SSA in a p-i-n diode embedded silicon microring resonator [4]. Here we extend our work and report cavity-enhanced SSA-induced photocurrent generation in a silicon microring resonator matrix.

Figure 1(a) shows the optical micrograph of the fabricated 2×2 microring resonator-based matrix comprising four microring-resonator-based add-drop filters (denoted as A to D). We fabricate the device on a silicon-on-insulator (SOI) wafer with a 0.34-μm-thick silicon device layer on a 1-μm-thick buried-oxide layer. Four square-shaped microrings are identically designed with rounded-corner radii of 15 μm and side interaction lengths of 20 μm. Figure 1(b) shows the cross-sectional schematic of the p-i-n diode integrated optical waveguide. The numerical simulation result shows the waveguide optical mode overlaps with the Si/SiO₂ interfaces which give rise to SSA. The p⁺ and n⁺ regions are doped with 2×10¹⁹ and 1×10²⁰ cm⁻³ and connected with aluminum pads. The intrinsic region width is 1 μm. The microring resonator effectively stores optical energy for a relatively long time and thus enhances photocurrent generation.

![Fig.1](a) Optical micrograph of our fabricated 2×2 microring resonator-based matrix. (b) Cross-sectional schematic of the p-i-n diode embedded silicon microring waveguide with numerically simulated waveguide mode profile.

We use a wavelength-tunable diode laser to perform optical transmission spectrum measurement in TE
polarization (electric field // chip). For photocurrent measurement, we use a pair of radio-frequency (RF) probes in contact with the p-i-n diode aluminum pads. The RF probes are connected to a precision semiconductor parameter analyzer.

Figures 2(a) and (b) show the measured transmission spectra and corresponding short-circuit photocurrent spectra with light launched at ports I1 and I2, respectively. The photocurrents at resonance wavelengths are at least 11 times (with a maximum of 28 times) enhanced compared with off-resonance photocurrent (background). The on-resonance photocurrents depend on four factors [4]: (i) the cavity quality factors, (ii) the resonance extinction ratios, (iii) the optical powers coupled into the waveguides, and (iv) the carrier collection.

We measure the current-voltage ($I$-$V$) curves at resonance D of wavelength 1553.84 nm upon various estimated coupled optical powers (Fig. 2(c)). Figure 2(d) shows the on-resonance photocurrent is linearly proportional to the coupled optical power, which is expected from SSA. The relatively high reverse bias voltages applied (-5, -10V) sweep out more photocarriers. Figure 2(e) shows responsivity of up to 0.15 mA/W and dark current of ~1 nA upon 10 V reverse bias. We also observe photovoltaic effect in the fourth quadrant of the I-V curves. Figure 2(f) shows the maximum generated electrical power of ~ 4 nW with 95 μW estimated coupled optical power, which corresponds to power conversion efficiency of $\sim 4 \times 10^{-5}$, consistent with Ref. [4].

Reference: