Photocurrent Generation in a Microdisk Resonator Integrated with Interleaved P-N Junctions

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Abstract: We investigate two-photon absorption (TPA) induced photocurrent generation in a microdisk resonator embedded with interleaved p-n junctions. Due to the strong electric field across the p-n junctions, free-carrier recombination rate is considerably reduced leading to an increased photocurrent.

OCIS codes: (230.5750) Resonators; (040.5160) Photodetectors.

1. Introduction

The relatively large bandgap of silicon above the communication wavelength (~1550 nm) keeps silicon photonic devices from being excellent near-infrared photodetectors. However, because photodetectors are one of the essential key components for multiple photonic integrated circuits, much research work has been devoted to improving the photocurrent generation in silicon devices. Devices based on mid-bandgap absorption (MBA), surface-state absorption (SSA), internal photoemission absorption (IPA), and two-photon absorption (TPA) have been reported with reasonable performances suitable for certain applications [1]. TPA effect can be very strong when using a high-Q cavity [2], but when the coupled light power in the cavity continues to increase, the free carrier absorption (FCA) will dominate and eventually the photocurrent becomes saturate [3]. The fundamental reason for photocurrent saturation is the high recombination rate of free-carriers at high coupled light power [4].

In this paper, we present a microdisk resonator integrated with periodically interleaved p-n junctions to enhance the photocurrent generation. Compared to a p-i-n diode with an intrinsic region width on the order of micron meters [2, 4], our structure has a much narrower depletion region of sub-micron meters wide. With the same reverse voltage, the electric field is much stronger in our structure, and hence the free-carriers generated by the TPA effect can be quickly swept out of the depletion region before they can recombine. As a result, the recombination rate is greatly reduced, resulting in a high photocurrent.

2. Device Structure

Fig. 1(a) shows the schematic drawing of the device. The waveguide is 400 nm wide and 220 nm high with a slab thickness of 60 nm. The radius of the microdisk resonators is 5 μm. The gap between the waveguide and the microdisk is 0.25 μm. The lightly doped P and N regions have a doping concentration of ~10^{17} cm^{-3}. The period of the interleaved p-n junctions along the disk rim is ~1 μm. The doping concentration of the heavily doped P$^+$ and N$^+$ regions is ~10^{20} cm^{-3}. The fabrication process is the same as in our previous work [5]. Fig. 1(b) shows the optical microscope image of the fabricated device. Figs. 1(c)-(e) show the simulated electric field distribution in one p-n junction under three biases of 0V, -4V, and -8V, respectively. The peak electric field increases with the reverse voltage and reaches ~4×10^5 V/cm at -8V. The short transit time of free-carriers under such high electric field makes it possible for high speed detection.

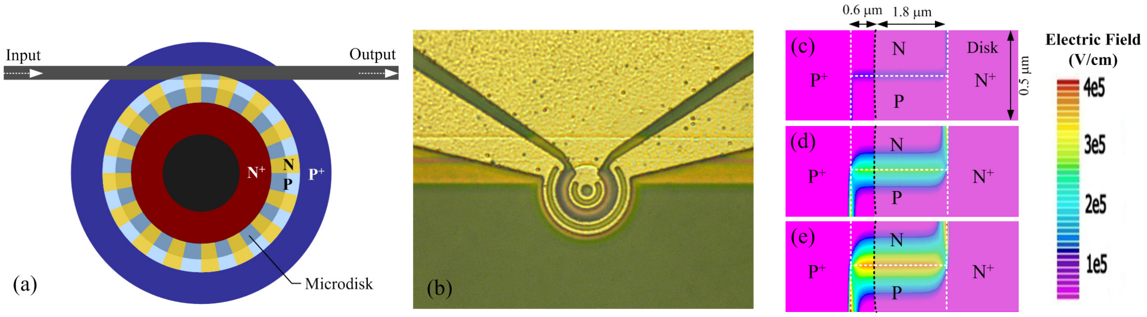

Fig. 1. (a) Schematic of the microdisk resonator embedded with periodically interleaved p-n junctions. (b) Optical microscope image of the device. (c)-(e) Electric field in one period of p-n junction at three bias voltages of (c) 0V, (d) -4V, and (e) -8V.

3. Experimental Results

Fig. 2(a) shows the measured transverse-electrically (TE) polarized transmission spectrum of the microdisk at an estimated coupled power (in the waveguide) of ~4μW. We selected the highest Q-factor (~6×10^4) mode with an extinction ratio of ~7dB around 1541 nm to study its photocurrent generation characteristic. Fig. 2(b) shows the resonance spectrum of the selected mode at the bias of -4V and the coupled power of 0.77 mW. The resonance line shape becomes asymmetric because of the free-carrier recombination induced thermo-optic nonlinear effect [6]. Fig. 2(c) shows the measured photocurrent spectrum in log scale around the selected mode. The line shape is very close to that in Fig. 2(a). The photocurrent at the resonance wavelength is over 5500 times higher than that at the off-resonance wavelength, revealing a very strong cavity-enhanced TPA effect. Fig. 2(d) shows the photocurrent as a function of the coupled power under various bias voltages in a log-log scale. The increment of the photocurrent only slightly slows down when the coupled power reaches ~0.1 mW at 0V bias. In comparison, the photocurrent gradually saturates when the input power exceeds a certain value as reported in the previous work where a p-i-n diode is used [3]. The inset shows the transmission spectra at various coupled powers at 0V bias, which suggests the free-carrier recombination is very strong. To reduce the recombination, we applied a reverse bias to the p-n junctions, making more TPA generated free-carriers convert to photocurrent rather than recombined. As a result, the photocurrent increases with the reverse bias as shown in Fig. 2(d). Meanwhile, less heat is generated resulting in a reduced temperature rise, which is confirmed by the blue-shift of the resonance spectrum in Fig. 2(e). High-speed characterization of the device is on-going.

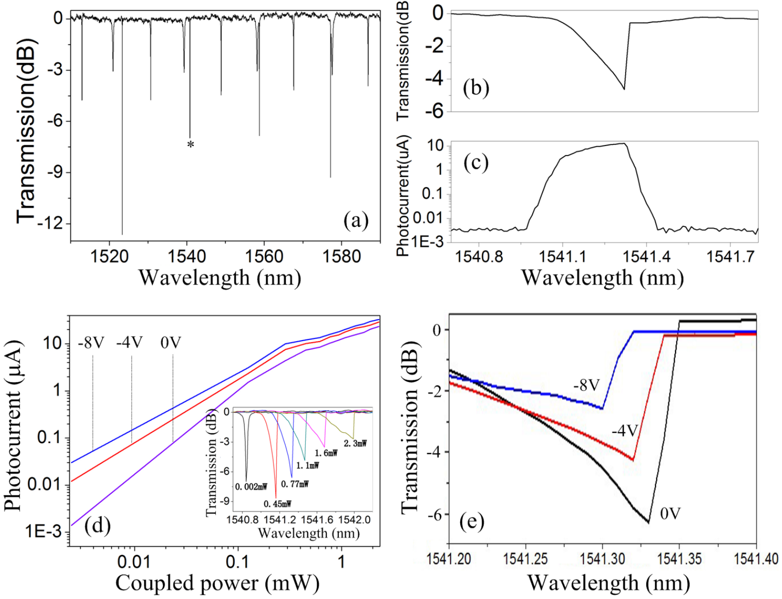

Fig. 2. (a) Transmission spectrum of the microdisk resonator. (b) Transmission spectrum around one resonance mode. (c)Corresponding photocurrent spectrum. (d) Peak photocurrent as a function of coupled power at various biases. Inset: resonance spectrum change with the coupled power under 0V bias. (e) Resonance spectra under various bias voltages. The coupled power is fixed at 0.77 mW.

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4. References

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