Plasmonic Au/Si microcone diode arrays for superior photodetection of near-infrared light

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Introduction

NIR photodetection is crucial for optoelectronics. Silicon detectors are low-cost and CMOS-compatible but bandgap-limited. Materials with narrower bandgap are hindered by high cost, fabrication complexity, or lattice-mismatch defects. Plasmonic hot electrons enable sub-bandgap detection by injecting across a Schottky barrier into Si. Au/Si Schottky detectors offer CMOS compatibility, low cost, and room-temperature operation. Here, A high-performance, broadband, polarization-insensitive, low-power NIR Schottky detector is reported.

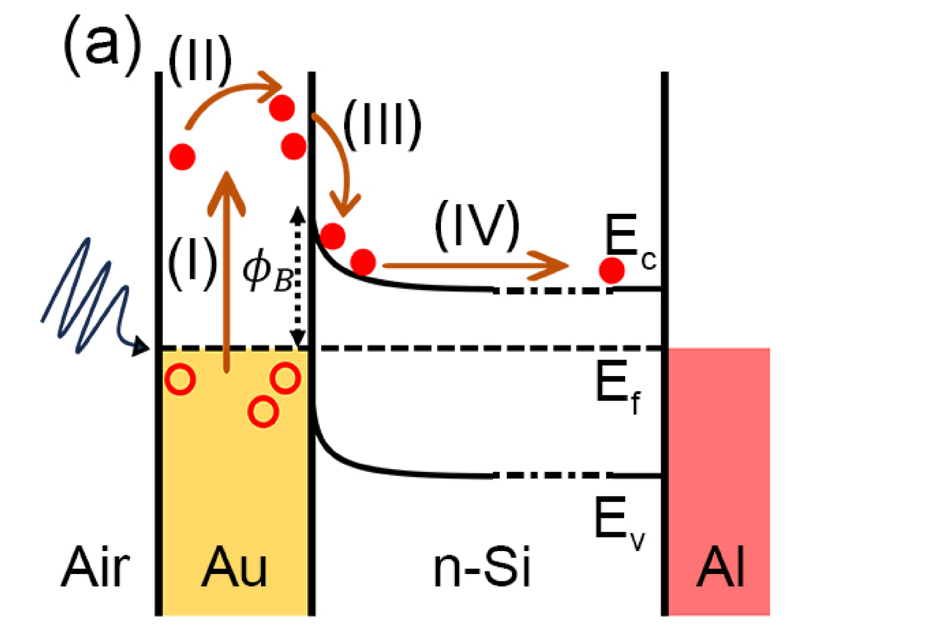

Fig. 1. (a) Schematic diagram of hot electron transport dynamics processes

Results & Discussion

Fabrication of Microcone Photodetector

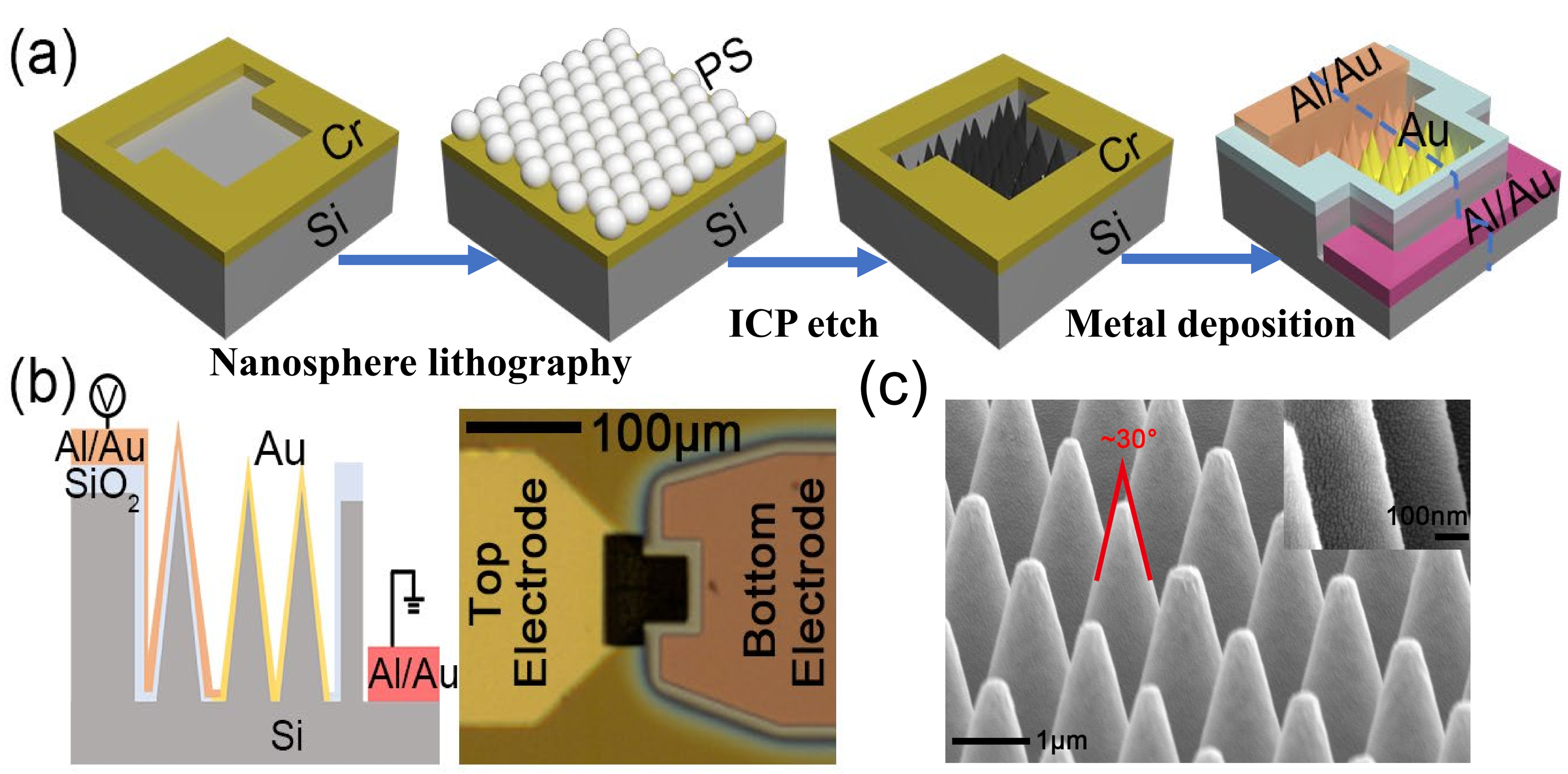

Fig. 2. (a) The schematic fabrication processes of the NIR photodetector. (b) the schematic cross-section image along the blue dashed line in (a) and the optical microscopy image of a device. (c) SEM image of Si microcones covered by a thin Au film

- Nanosphere lithography was used via a modified Langmui-Blodgett technique.
- By adjusting etching conditions, the apex angle and size of microcone can be modulated.

Optoelectronic Characteristics

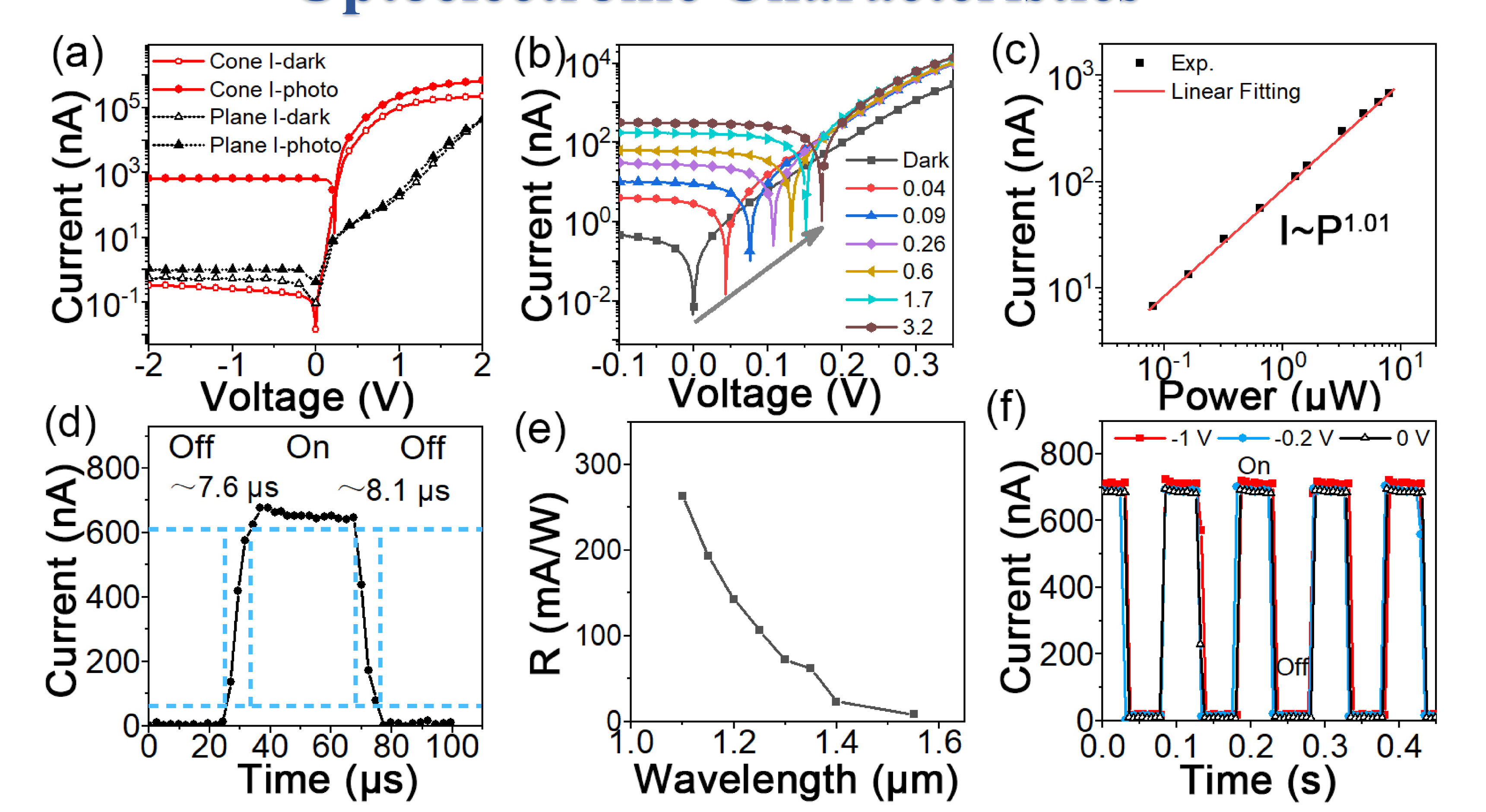

Fig. 3. (a) The typical I-V curves of Schottky PDs based on microcone and reference plane structure. (b) The I-V curves under different powers (in μW) of incident light. (c) The photocurrent as a function of light power at -1.0 V bias voltage. (d) the Rise/Fall time(10%-90%) of photocurrent for periodic illuminations. (e) the responsivity *vs* wavelength at -1.0 V bias voltage. (f) the fitting of wavelength-dependent responsivity based on the Fowler model

- The microcone Schottky PDs demonstrates a dramatic enhancement by a factor of over ~2900 in responsivity.
- The device supports a pronounced self-powered and broadband photodetection.

Strategies for the Optimization

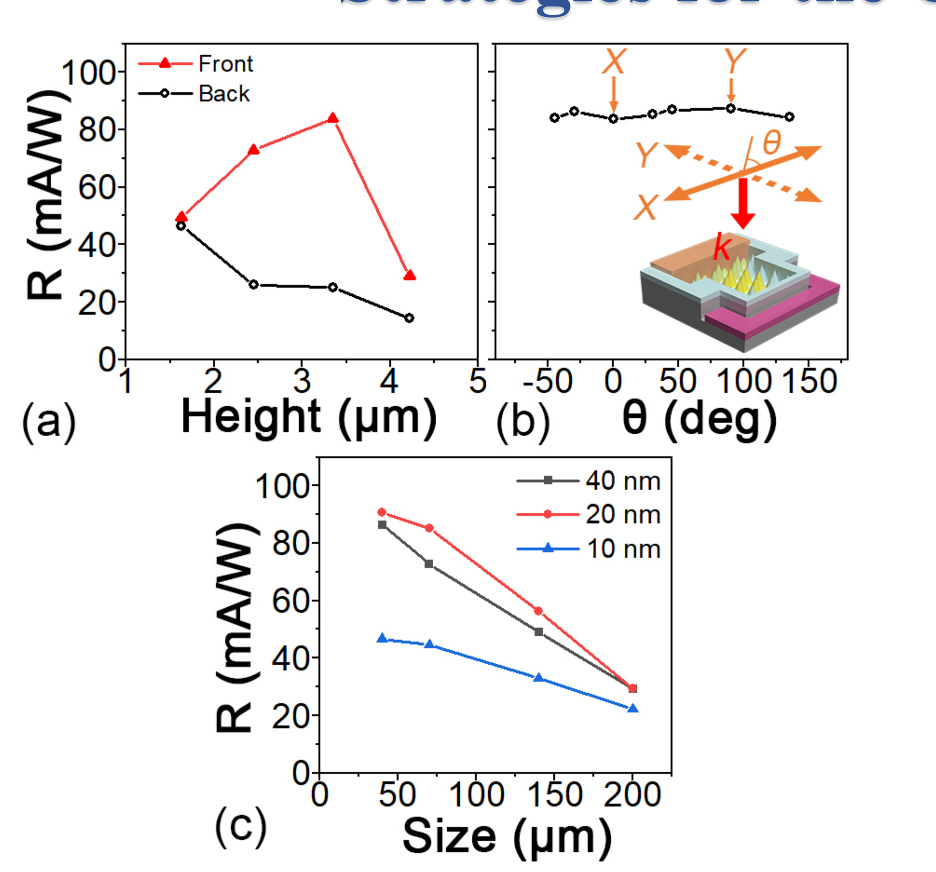

Fig. 4 (a) Responsivity vs the height of microcones for front-side (red solid) and back-side (black open) incidence of light, (b) responsivity vs the polarization angle θ of incident light. The angle θ denoting the polarization and the wave vector K of incident light is schematically shown in the inset, (c) responsivity vs the size of photodetectors with different Au film thicknesses of 10, 20 and 40 nm.

- The microcone height, device size and Au film thickness have a significant impact on the responsivity due to the generation, transport, and emission of hot electrons.
- The microcone PD is polarization-insensitive.

Optical/Electrical Simulation

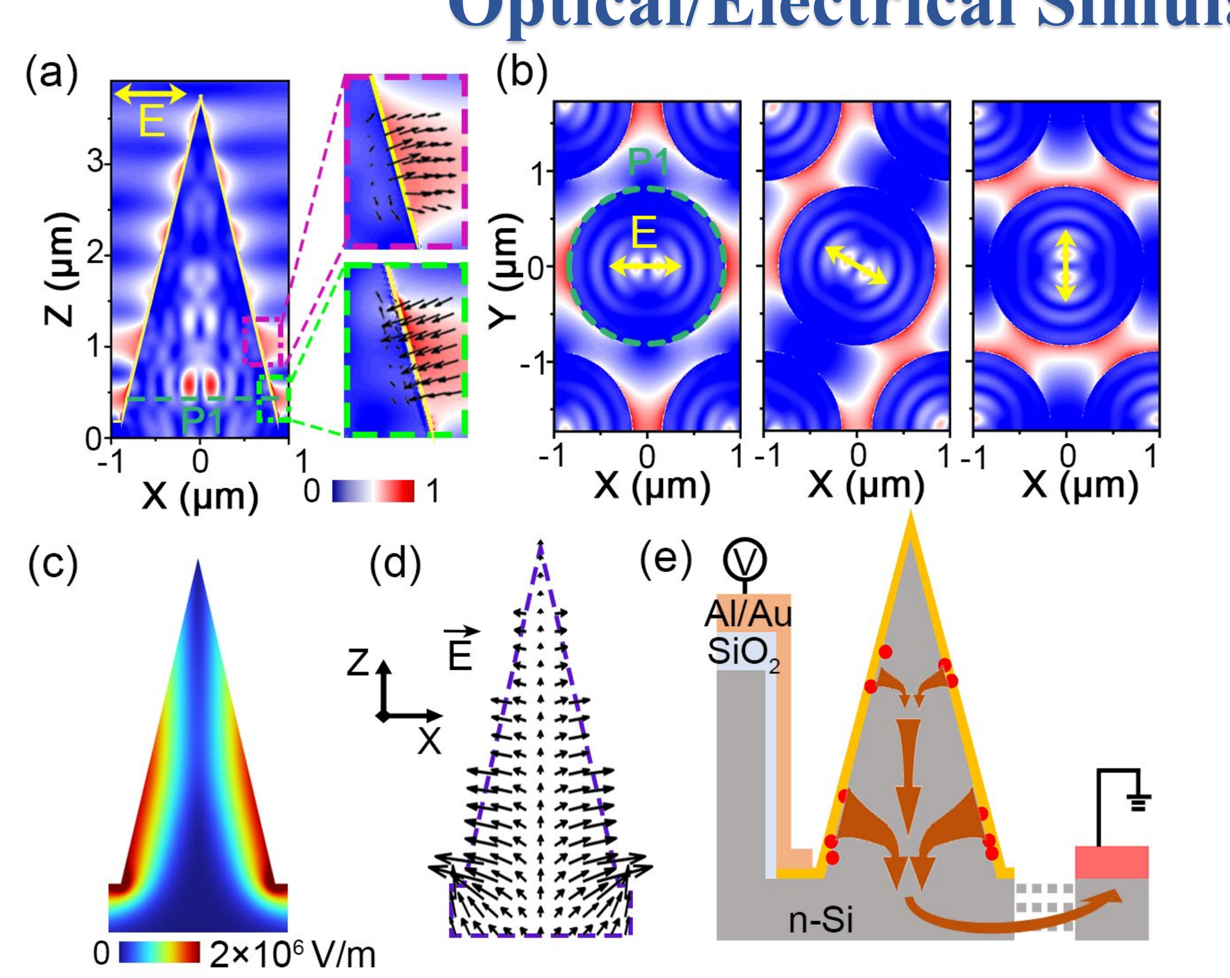

Fig. 5 (a) The light field distribution in the plane of polarization. (b) the in-plane light field distribution for different polarizations. (c) the strength, (d) the direction distribution of E field in the cross-section of microcone. (e) Schematic diagram of microcone detector with the collection path of hot electrons.

- The abnormal SPP and light field distribution of standing-wave-like pattern affect PD performance significantly.
- The unique E field shows the transport path of hot electrons.

Conclusion

A broadband, polarization-insensitive near-infrared Schottky photodetector based on an Au/Si microcone diode array is reported. It achieves record zero-bias responsivity of 79 mA/W, noise equivalent power 2.6×10^{-14} W, specific detectivity 1.8×10^{11} Jones, and ~8 μs response at 1.31 μm. The performance originates from the nanoantenna effect and abnormal standing-wave-like surface plasmon polariton of the 3D Au microcone-shell, which boost light absorption and hot-electron generation. Simultaneously, the unique electric field distribution within the Si microcone enables efficient hot-electron collection. Optimizing microcone size and electrode spacing can further improve responsivity. This self-powered detector is ideal for energy-saving portable optoelectronics and advances silicon-platform integration.