Planar and Vertical Si Nanowire Photodetectors

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Abstract: We demonstrate scalable Si nanowire photodetectors that function as phototransistors. Etched planar and vertical Si nanowire photodetectors have been fabricated and characterized, showing high (>35,000) internal gain under UV illumination.

OCIS codes: (040.5160) Photodetectors; (040.6040) Silicon Detectors

1. Introduction

Si photodetectors have a myriad of uses from optical interconnects to image sensor arrays. Si nanowires (NW's) can behave as phototransistors, displaying significant phototransistive gain due to charge carrier separation by the internal field transverse to the nanowires. The unique optoelectronic properties and device size make Si NW's attractive to visible and UV detection. Previous studies on CVD grown wires[1, 2] and planar-etched devices[3] have not addressed the magnitude and mechanism of gain in detail. Here we demonstrate both planar and vertical Si NW photodetectors with significant gain and characterize the strong nonlinear gain effect in NW detectors.

2. Experimental methods

Planar Si NW photodetectors were fabricated from a p-type SOI wafer with a 230nm Si layer and 380nm buried oxide. Oxide was optically patterned on top of the device layer and KOH was used to etch completely to the buried oxide. Subsequently, Ni was deposited and annealed to form Ni silicide and a final metallization of Al was deposited. Figure 1(a) shows an SEM of the resulting device for multiple wires. Vertical Si NW's were created on a p-type Si wafer using E-beam patterned Ni dots as a mask for anisotropical dry etch. The high aspect ratio Si nanowires were produced using C_4F_8:SF_6 ICP/RIE etch process at room temperature. These devices are shown in Figure 1(b). IV characteristics in dark and under UV illumination were performed using a filtered Hg vapor lamp with a filter pass-band centered at 390nm (±50nm). The devices were directly probed and measured using an Agilent 4155B parameter analyzer. Vertical wires were contacted at the Ni contact on the top of the wires, and on the backside contact.

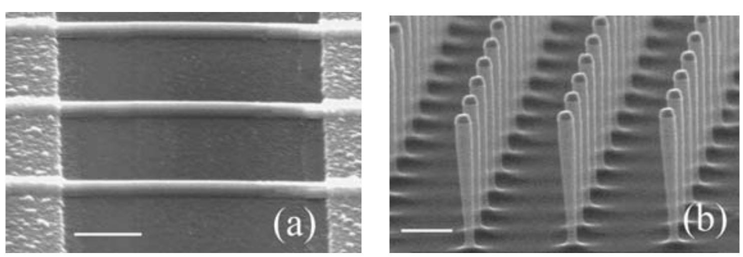

Fig. 1. (a) SEM of multi-wire planar-etched Si NW photodetector on SiO_2. The wires are approximately 250nm in diameter and 8µm in length. The device has Al contacts above Ni silicide. Scale bar is 2µm. (b) SEM of an array of vertically etched Si NW's with top Ni contacts with diameter 150nm and length 1.5µm. The scale bar is 500nm.

3. Results and discussion

IV curves of vertical devices in dark and under UV illumination are shown in Figure 2(a) and are representative of device behavior for both vertical and planar structures. The non-linear IV indicates non-ohmic contacts to the device. Strong gain saturation is seen with increasing light intensity. However, a quantitative estimate of gain is unachievable with vertical NW detectors because the light power incident upon the vertical wires is unknown due to shadowing of the device by the probe. Instead, the gain dependence on light intensity for a planar 10 NW device is provided in Figure 2(b). The gain of the nanowire phototransistor is the ratio of the trapped time of the trapped carriers (acting as gate bias) and the transit time of the free carriers. Experimentally, this corresponds to the ratio between photocurrent (# electrons/sec) and photon flux (# photons/sec). The photon flux incident on this planar device is estimated at a given light intensity assuming all 10 NW's, each having an area of 250nm x 8µm, in an

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array are exposed, and 33% of the incident 390nm light is absorbed due to 45% surface reflection and 60% absorption in the 230nm NW depth at λ=390nm. This results in a substantial gain of over 35,000 at the lowest light intensity, which quickly saturates at higher intensities. This is a promising result for low-light intensity applications as it suggests that as the light intensity is further reduced, the gain will continue to increase, allowing for detection approaching the single photon limit.

The gain seen in these NW devices is indicative of an extended carrier lifetime. As seen in other NW devices, such as ZnO NW's[4], the structure of the NW greatly enhances recombination lifetime through spatial charge separation. This is similar to a phototransistive behavior where carriers accumulated at the surface act as an optically modulated gate. As previously shown by quantum dot phototransistors [5], the increase in recombination lifetime greatly enhances the gain allowing for detection down to single photon resolution. This effect is enhanced in NW's due to the increased surface to volume ratio.

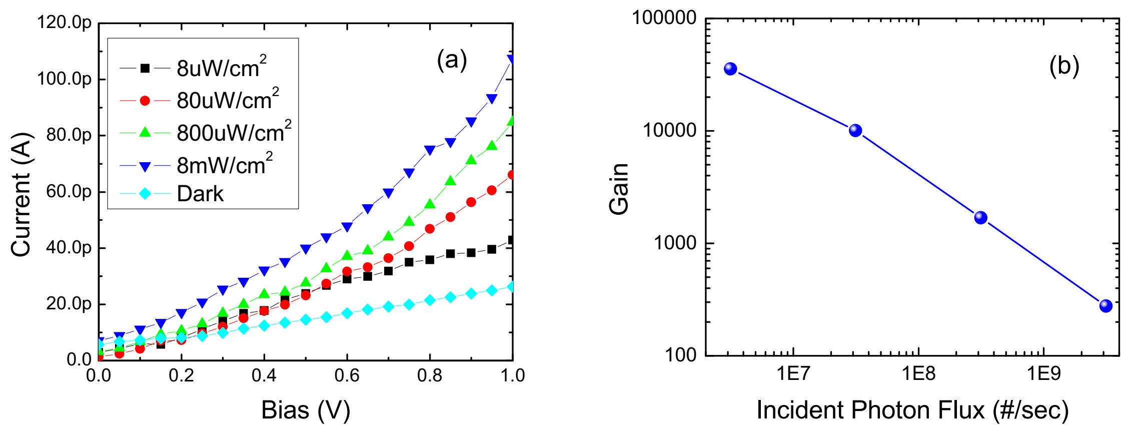

Fig. 2. (a) IV curves of vertically etched NW's in dark and under various UV illumination intensities. (b) The estimated gain of a 10 NW planar device biased at 0.5V vs photon flux, demonstrating gain saturation at higher light intensities.

4. Conclusion

Si NW photodetectors have been fabricated through anisotropic etching to create both planar and vertical arrayed devices. Characterization of these devices under UV illumination shows that a high gain of 35,000 at low light intensities is achievable due to an increased carrier recombination lifetime which is enhanced by the NW structure. This demonstrates the potential for creating highly sensitive, scalable photodetector arrays.

5. Acknowledgements

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6. References

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