Asymmetric group IV MSM photodetectors with reduced dark currents

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Abstract: Effective dark current suppression in metal-semiconductor-metal photodetectors (MSM-PD) using asymmetric metal electrodes is demonstrated. Improved signal-to-noise ratios normalized to input optical power (NSNR) as high as ~800mW^{-1} is achieved for Ge MSMs.

OCIS codes: (040.5160) Photodetectors; (040.3060) Infrared

On-chip optical interconnections for global signaling or clocking are promising to eliminate many problems associated with large multi-GHz Si-IC chips, e.g. removal of timing skew, reduction in power and area for clock distribution [1]. In such applications, detection wavelength transparent to Si, like near infrared (NIR), can be used to avoid generating extra circuit noise. Extensive research has been focused on III-V semiconductors for NIR optical detection; however, integration with the advanced Si CMOS technology is difficult [2]. Ge represents the best alternative material for detection in NIR and can be monolithically integrated with the well-established Si VLSI technology [3].

Low detector capacitance, internal optical gain, ease of integration, and high device bandwidth are attractive characteristics of MSM-PDs, however, the relatively large dark currents (I_{dark}) pose high static power dissipation. To circumvent this problem, we demonstrate for the first time by both simulations and experiments I_{dark} reduction by selectively adjusting the Schottky barrier heights with asymmetric MSM-PDs.

Simulations were done in ATLAS™ on a Si-based MSM structure to verify the theoretical motivation. Illustrated in Figure 1 is the simulated photo and dark current characteristics of a Si-MSM. An increase of 0.35eV in the electron injection barrier on the reverse-biased electrode drops I_{dark} by 10^5 times without apparent sacrifice of photocurrent (I_{photo}). Figure 2 shows the experimental data from both symmetric and asymmetric interdigitated Si-MSMs. Asymmetric detectors result in ~2 order of magnitude I_{dark} (noise) lowering without significant I_{photo} (signal) degradation, exhibiting the functionality of the proposed scheme.

Applying the same concept in Ge photodetectors, Ti, Cr, and Ni were used to build both symmetric and asymmetric MSMs. 1480nm laser illumination was arbitrarily chosen for a quick verification of detector photoresponse, as the I_{dark} suppression mechanism should be wavelength independent. NSNR were employed as performance metric to minimize any optical power variation between measurements. NSNR values are substantially higher for asymmetric MSM-PDs than their symmetric counterparts as show in Figure 3. MSM-PDs with different electrode width, electrode spacing, and active detection areas were also examined showing similar behavior.

We have demonstrated a remarkable dark current suppression scheme in MSM-PDs on Group IV semiconductors by preferentially modifying the Schottky barrier heights. No corresponding decrease in photocurrent was observed. Normalized SNR values exceeding those for symmetric MSMs were achieved. Such detectors would envision many applications in future low-power on-chip optical interconnects and telecommunications.

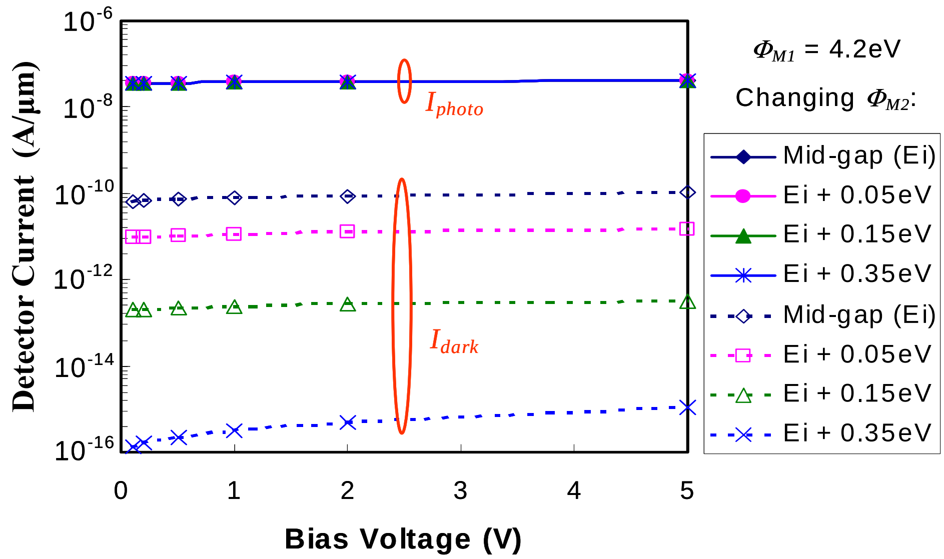

Fig. 1. Simulated photoresponse of Si-based asymmetric MSM showing a huge reduction in I_{dark} without significant decrease in I_{photo}. Simulation is done at λ=623nm and 5W/cm^2 optical excitation on 1µm finger width and 2µm spacing devices.

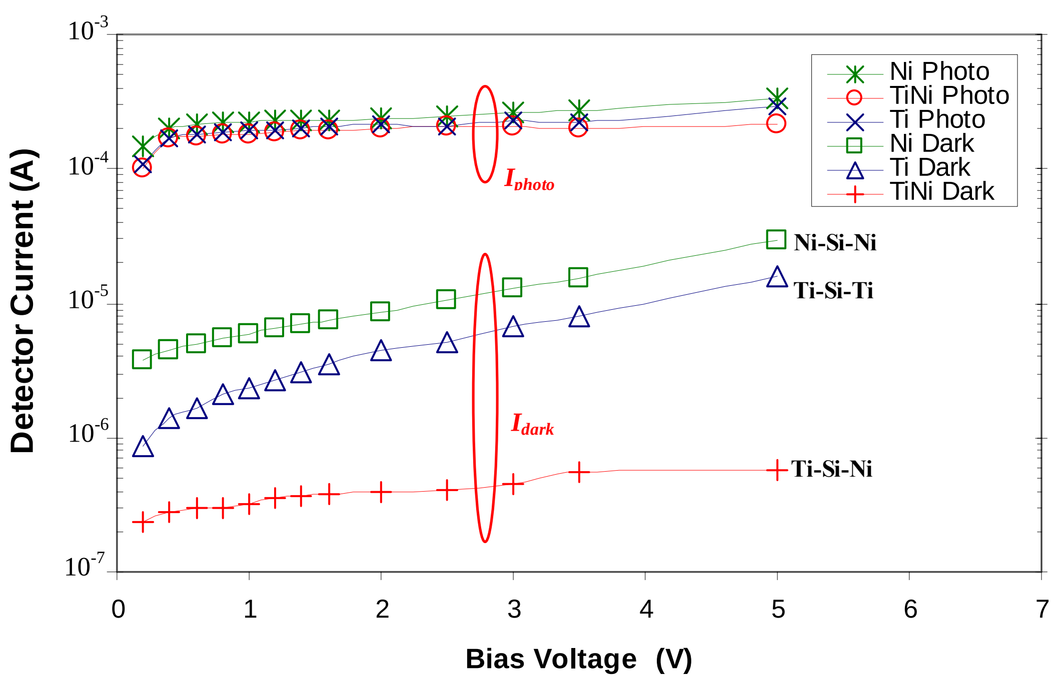

Fig. 2. Experimental photoresponse and dark current from a Ti-Si-Ni asymmetric MSM-PD compared to Ti-Si-Ti and Ni-Si-Ni symmetric cases. Detectors with 5µm finger width and spacing on lightly p-doped Si were excited by a 632nm, 5mW laser.

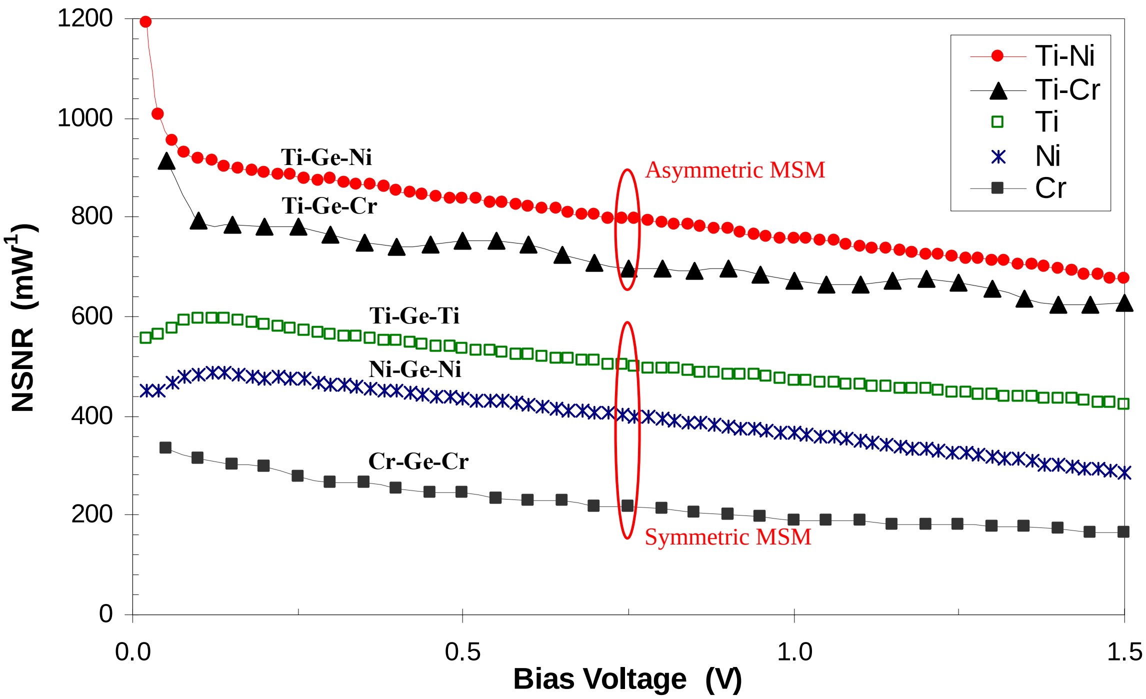

Fig. 3. NSNR versus applied bias. Asymmetric MSM-PDs and their symmetric counterparts are plotted together. A significant enhancement in NSNR is observed for the asymmetric detectors. All detectors have 5µm finger width and spacing and active area of 0.01mm^2 on lightly n-doped Ge.

References

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