Rapid Melt Grown Germanium Gate PhotoMOSFET on a Silicon Waveguide

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Abstract: We demonstrate the first monocrystalline germanium gate photoMOSFET integrated with silicon photonic waveguides and grating coupler. We measure a responsivity of 1.2 A/W at 1550nm with a 2x4 μm^2 germanium gate.

I. Introduction

Nanoscale photodetectors offer many benefits for optical interconnect applications[1]. Low capacitance provides for large photovoltage and reduced gain requirement, reducing the overall energy consumption of the receiver and increasing bandwidth. Since wires connecting the photodiodes to logic stages have capacitance ~0.2 fF/μm, even relatively short wires will dramatically increase the total capacitance of the photodiode[1]. To circumvent this issue it has been proposed to totally eliminate the wire by directly integrating the photodiode and the first transistor of the gain stage using a germanium-gated MOSFET[2]. The use of polycrystalline germanium, which has a very short recombination lifetime, as the gate material likely hampered experimental verification of the device simulation results, however[2]. Additionally the device had poor optical coupling because the gate was thin and not integrated with a silicon waveguide. A germanium-based photoJFET fabricated on a silicon waveguide had low responsivity (0.64 A/W) due to defects because its germanium was grown directly on silicon[3].

We solve these issues by using a monocrystalline germanium gate formed by rapid melt growth[4] for longer carrier lifetimes and higher gain, and fabricate it directly on a silicon waveguide for good optical coupling. The fabricated germanium gate photoMOSFET is demonstrated to have a responsivity of 1.2 A/W at 1550 nm.

II. Device Design and Fabrication

Fig. 1a shows a schematic cross-section of the MOSFET, showing the silicon source, drain, and body, and germanium gate. In addition to the germanium gate, a novel feature is the 220 nm SOI body which also functions as a waveguide to transmit light into the transistor. The light can then evanescently couple into the germanium gate region. When light is absorbed, the electric field in the partially depleted gate forces holes towards the gate oxide, and electrons to the gate electrode. Holes accumulating in the gate near the oxide increase the effective gate voltage and thereby the channel inversion layer charge, resulting in increased drain current. The top view of a completed photoMOSFET is shown in Fig 1b.

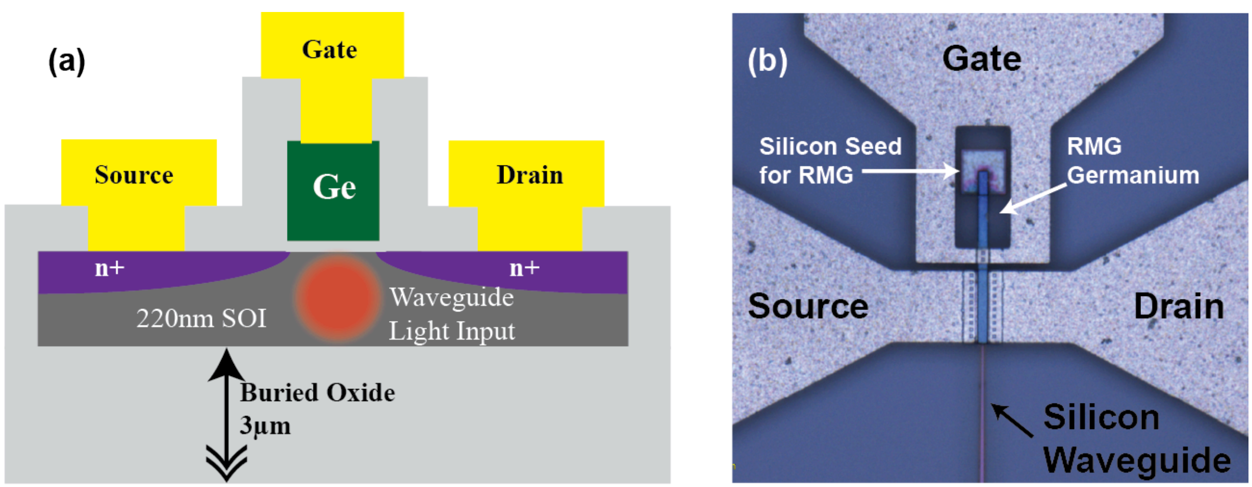

Figure 1 (a) Schematic cross section of the germanium gate phototransistor on SOI waveguide. (b) Optical microscope top-view image of fabricated photoMOSFET with 2 μm gate length and 16 μm channel width.

A 220 nm p-type (10^{15} cm^{-3}) SOI wafer with a 3 μm buried oxide layer is first implanted with Boron at 30 keV with a 10^{12} cm^{-2} dose. Regions of the SOI are patterned to form waveguides with grating couplers. After a 17 nm thermal oxide is grown, it is patterned to define the seed-Si area and etched with dilute HF just prior to 350 nm germanium deposition by LPCVD. After the germanium is patterned into thin ridges, the source and drain are formed by a self-aligned Phosphorus implantation at 20 keV with a 2×10^{15} cm^{-2} dose, which also moderately dopes

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the gate n-type. After depositing a 300 nm LTO capping layer the devices are annealed for 1s at 1000°C by RTA. Contact via holes are etched into the oxide, and a sputtered 50nm/400nm Ti/Al metal stack is patterned with contact pads.

III. Electrical Characterization of MOSFET and Photocurrent

A 2 µm × 4 µm (channel length × channel width) device was electrically characterized using two DC voltage supplies and a picoammeter, with and without a 1550 nm laser coupled into the waveguide through a grating coupler with an angled fiber for a total power of 10 µW. The grating couplers were measured to have 20 dB of insertion loss, due to a lithography error red-shifting the designed wavelength away from 1550 nm. Additionally the waveguides were not masked during the Boron implant, so that free carrier absorption is significant. Fig 2a shows the measured drain current as a function of gate voltage, for drain-to-source voltage equal to 1.5 V. The threshold voltage (V_T) in darkness is 1.5 V, while it is 1.4 V with 10 µW of light, indicating a V_T shift of 100 mV. Fig 2b shows the MOSFET output characteristics for two gate voltages, both with and without light. These results clearly show that the light is acting as an additional gate voltage, *i.e.* the behavior is unlike that of a traditional photodiode.

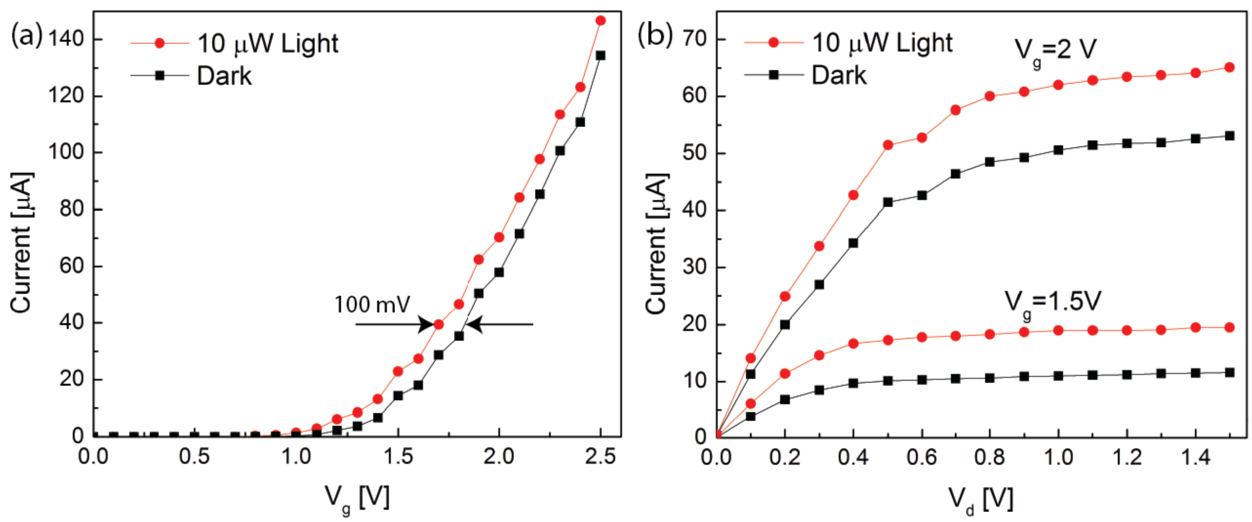

Figure 2. (a) Measured drain current versus gate voltage, for a drain-to-source voltage of 1.5 V. (b) Measured drain current versus drain voltage for two gate voltages.

IV. Conclusion

We have fabricated a germanium gate photoMOSFET integrated directly with a silicon waveguide. A 2 µm × 4 µm device was shown to have a responsivity of 1.2 A/W with 10 µW waveguide input power at a gate bias of 2 V and drain bias of 1.5 V with 53 µA of dark current. The light response presents itself as a threshold voltage shift in the device, which paves the way for improvements by using well-established approaches reducing MOSFET parasitic capacitances, threshold voltage and subthreshold swing.

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