Four-quadrant Silicon and Silicon Carbide Photodiodes for Beam Position Monitor Application: Electrical Characterization and Electron Irradiation Effects

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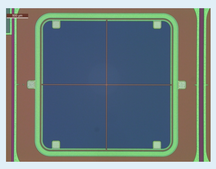
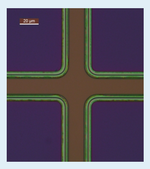
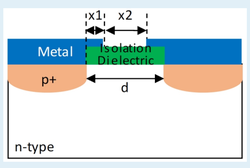
Introduction

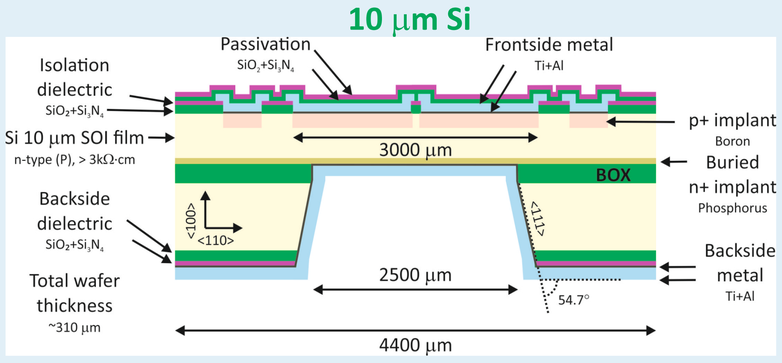
Silicon photodiodes are very useful devices as **X-ray beam monitors** in **synchrotron** radiation beamlines. In order to be used in **transmissive mode** and given the absorption properties of silicon, the devices must be **thinner than 10 μm** to achieve X-ray transmission higher than 90% for photon energies above 10 keV. On the other hand, **bulk silicon** segmented devices are also of interest for **astronomy** and **space applications**, such as solar tracking systems. Owing to their **lower susceptibility** to variable **temperature** and **illumination** conditions, there is also a special interest on **silicon carbide** devices for some of these applications. Moreover, **radiation hardness** of the involved technologies is a major concern for **high-energy physics** and **space applications**

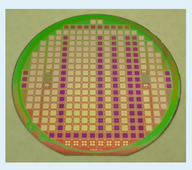
Fabricated 4-quadrant diodes on 3 substrates

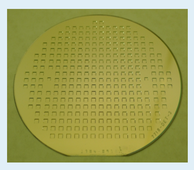
Single and **4 quadrant diodes** with **different geometries** for interquadrant distance & metal layer. **MOS capacitors** with **interquadrant isolation oxide**

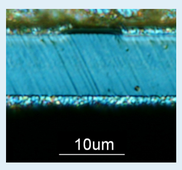




10 μm Si

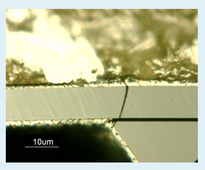



Wafer front side


Wafer back side

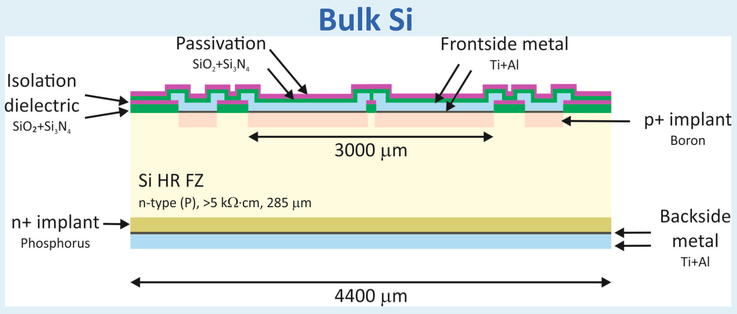


SOI film

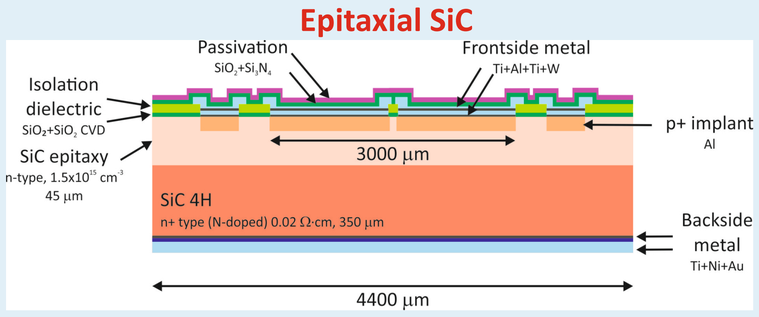


Back etch corner

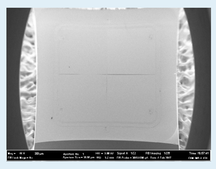
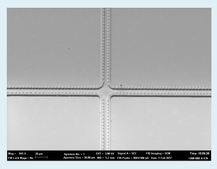
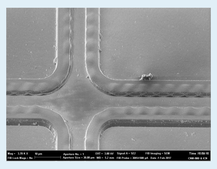
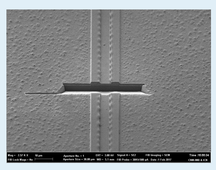
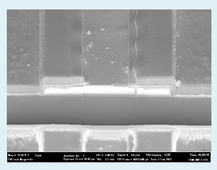
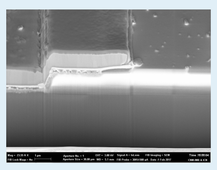
Bulk Si



Epitaxial SiC



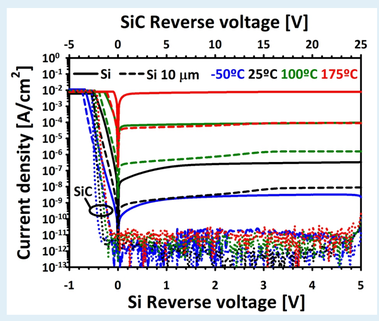
Inspection: **Optical Microscopy,** **Scanning Electron Microscopy** (SEM), **Energy Dispersive X-ray Spectroscopy** (EDX), **Focused Ion Beam** (FIB)

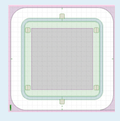







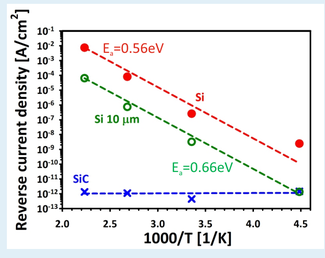
Summary: Four-quadrants diodes have been fabricated on **bulk Si**, **ultrathin Si** and **epitaxied SiC** substrates. The **improved performance** shown by **SiC** devices at **variable temperature** and **visible light illumination** conditions could simplify some **applications experiments** in which silicon devices are used. However, **radiation-induced behavior** at high irradiation fluences, as well as **further SiC technology** developments to process on high resistive (semi-insulating) bulk SiC substrates, **need to be further studied**

Electrical characterization & 2 MeV e- irradiation

Temperature effects

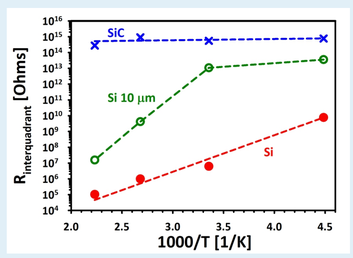




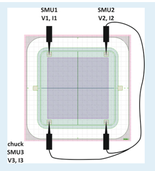


T ↑ ⇒ Si, Si 10 μm: $I_{reverse}$ ↑, I_{direct} ↑ — SiC: $I_{Reverse}$ ↔ (E_{gSi}<E_{gSiC} ≈ 3.2 eV), I_{direct} ↑ ($n_i(T)$↑⇒$V_{th}(T)$↓)

Reverse bias diode breakdown (>40 V for Si 10 μm, >100 V Si & SiC)

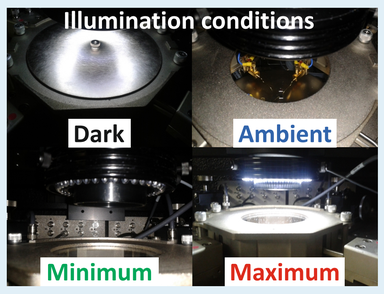


$$R_{interquadrant} = \frac{1}{\frac{dI_1}{dV_2}}$$



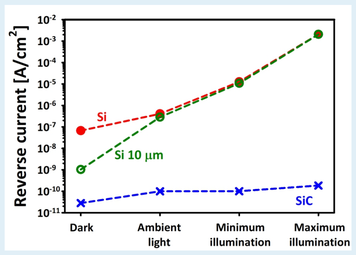
T ↑ ⇒ Si $R_{interquadrant}$ ↓, Si 10 μm $R_{interquadrant}$ ↓, SiC $R_{interquadrant}$ ↔

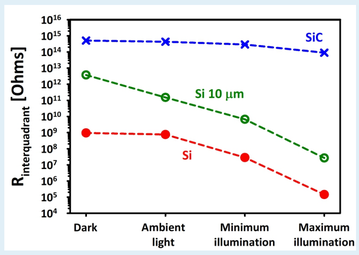
Visible light effects



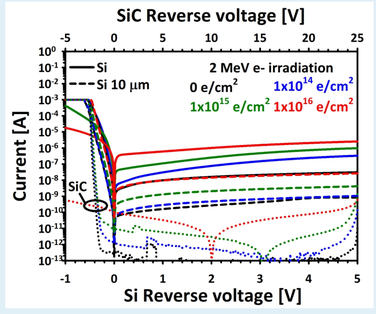
Visible light ↑ ⇒ Si $I_{reverse}$ ↑ $R_{interquadrant}$ ↓, Si 10 μm $I_{reverse}$ ↑ $R_{interquadrant}$ ↓, SiC $I_{reverse}$ ↔ $R_{interquadrant}$ ↔

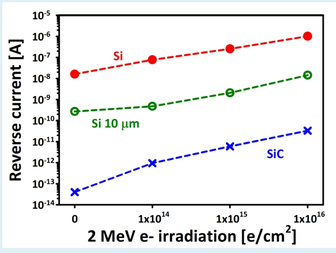
Visible light: 400 nm-700 nm (3.1 eV-1.65 eV)





2 MeV e- irradiation effects

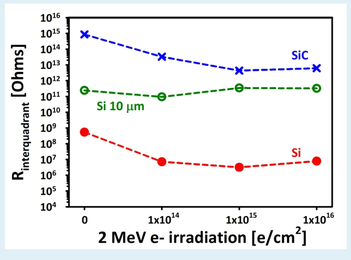


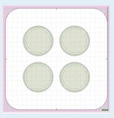


e-irradiation ⇒ $I_{reverse}$ ↑ Si, Si 10 μm & SiC

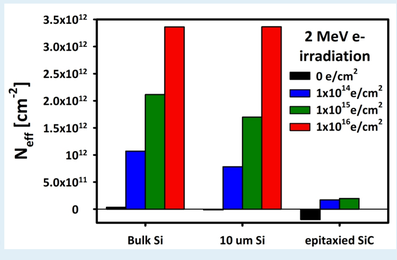
Relatively low $I_{reverse}$ in SiC diodes for 1x10^{14} and 1x10^{15} e/cm^2 however, no clear diode for 1x10^{16} e/cm^2 (needs further SiC studies)

Si bulk: e-irradiation ↑ ⇒ I_{direct} ↓ (R_{series} ↑ ?)





MOS C-V Isolation oxide charges



e-irradiation ⇒ Si, & SiC $R_{interquadrant}$ ↓, Si 10 μm $R_{interquadrant}$ ↔

positive charge buildup in Si & Si 10 μm isolation dielectric (SiO_2+Si_3N_4)

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