Reliability and total dose effects in Germanium p-MOSFETs

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Motivation & Goals

✧ Importance of Germanium, III-V MOSFETs to 22 nm (and beyond) technology node

✧Understanding effect of basic parameters (e.g. E_g, n_i) on Ge MOS characteristics

✧Effects of total dose radiation on state of art Ge p -MOSFETs

✧Influence of variation in process parameters on total dose response

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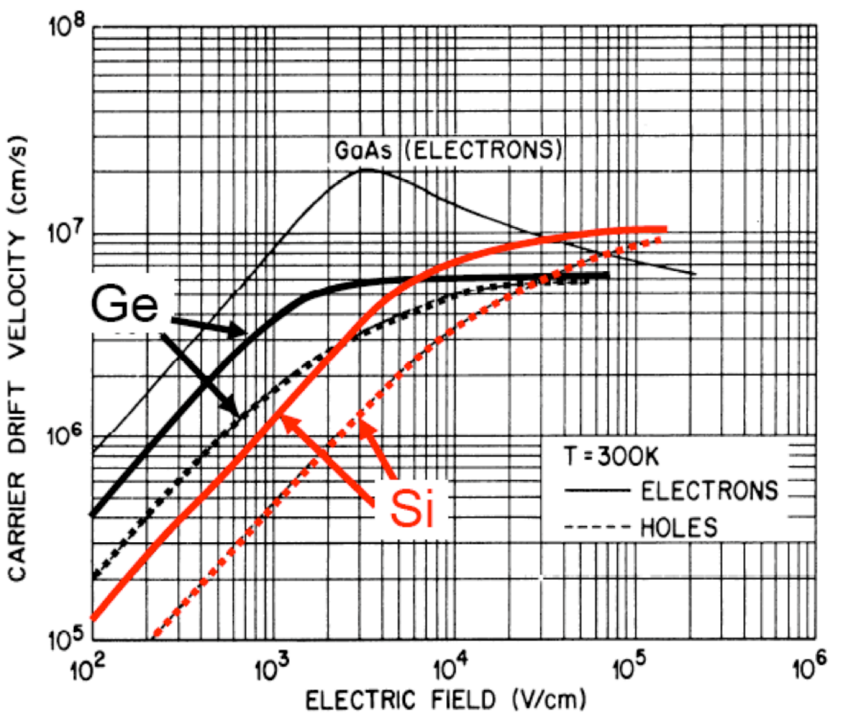
Ge p-MOSFETs for 22 nm technology node



D_{it} is asymmetric in the band gap:

- higher density (of the order of 10^{13} cm^{-2} eV^{-1}) near the conduction band
- lower trap density (of the order of 10^{12} cm^{-2} eV^{-1}) near the valence band

- higher electron (2.5X) and hole (4X) bulk mobility relative to that of Si
- p-channel HfO_2/Ge MOSFETs with EOT down to 0.85 nm, exhibiting higher hole mobility compared with HfO_2/Si control samples have been reported
- V_{dd} scaling makes it possible to use low bandgap materials
- Low processing temperature of Ge MOSFETs ⇨ compatibility with 3-D IC integration

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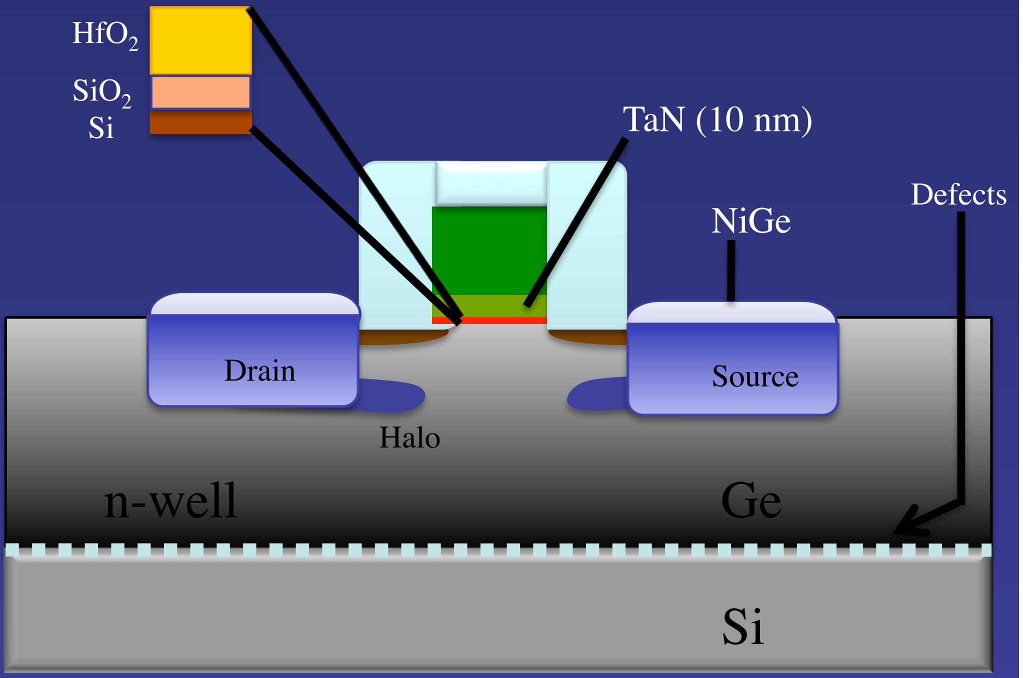
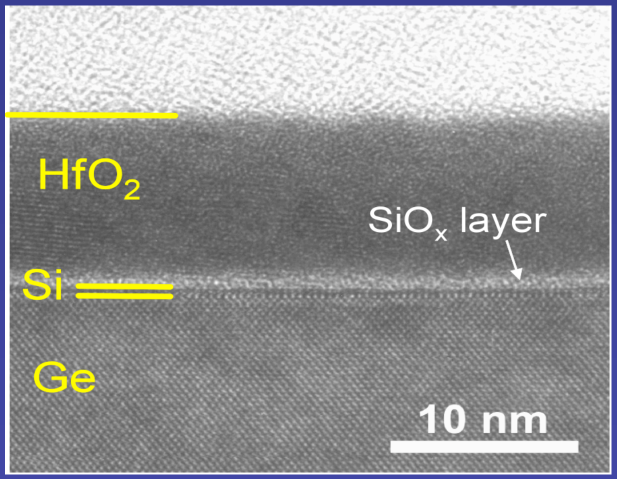
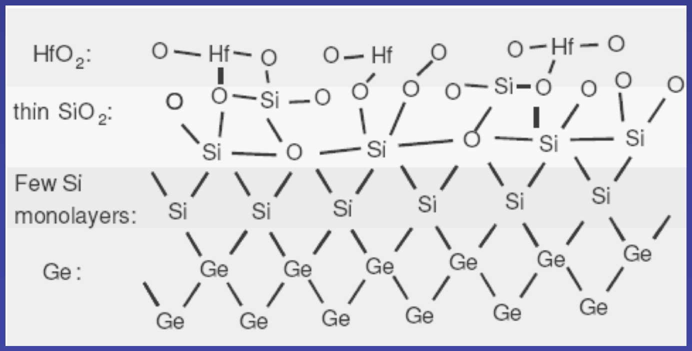
Device Details

- Ge p-MOSFETs – HfO_2 high-κ
- SiO_2/Si interlayer, TiN/TaN gate metal
- Variation in halo doping
- Variation in Si monolayer thickness







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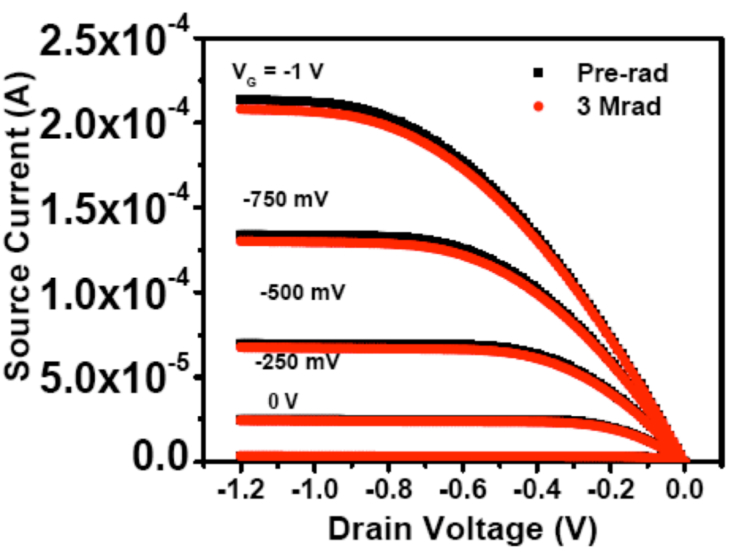
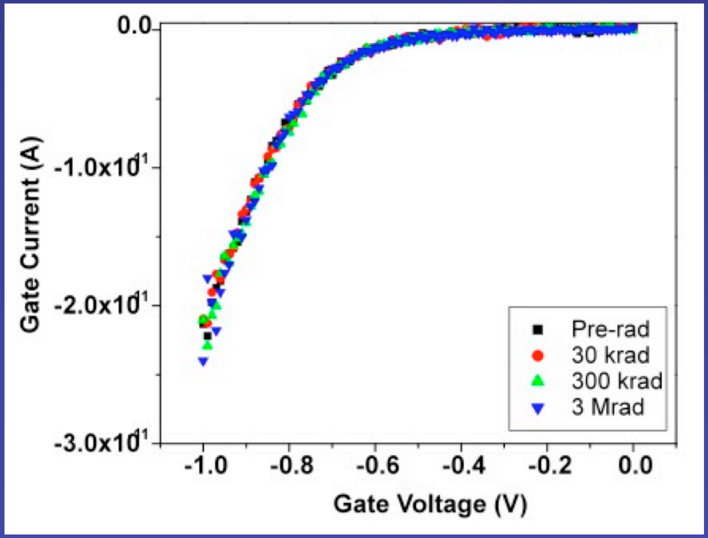
Total dose radiation study on Ge p-MOSFETs: Basic mechanisms

No significant decrease in mobility reported with x-ray dose.

No Change in gate leakage characteristics





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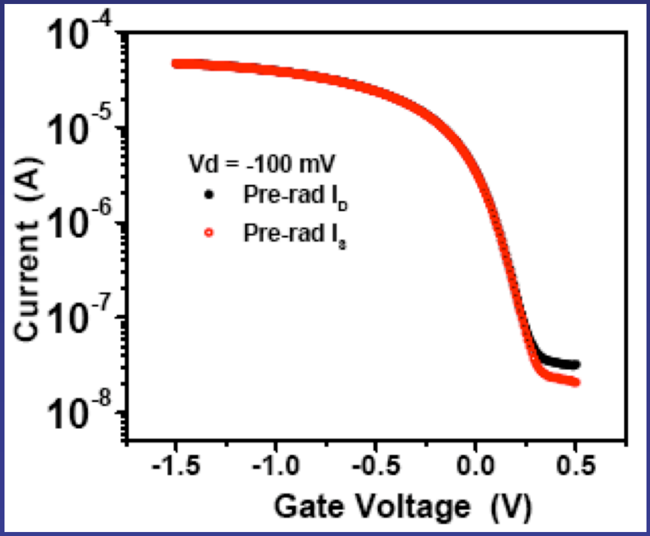
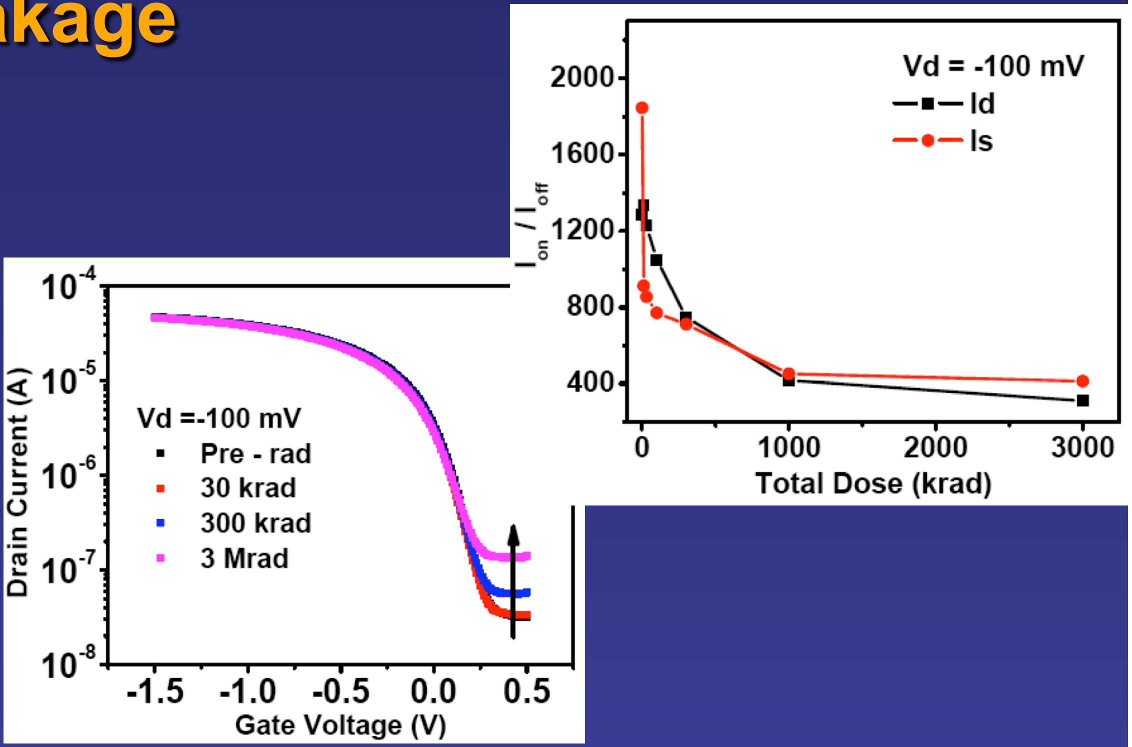
Junction leakage





- Difference in off-state current in prerad condition between source and drain terminals
- With total dose radiation the off-state leakage gets worse
- Consistent increase in off-state current results in degraded *Ion/Ioff* ratio

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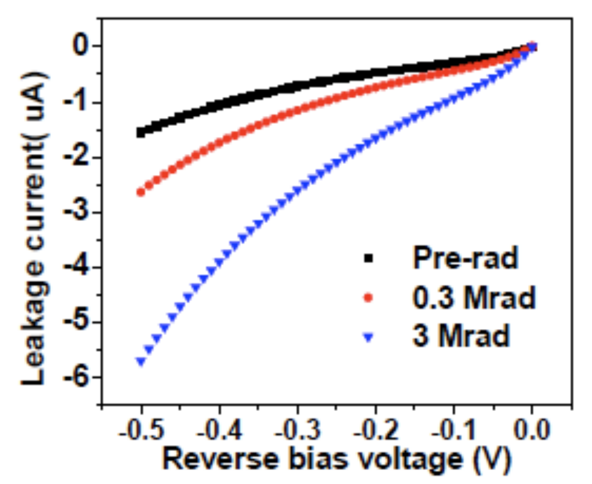
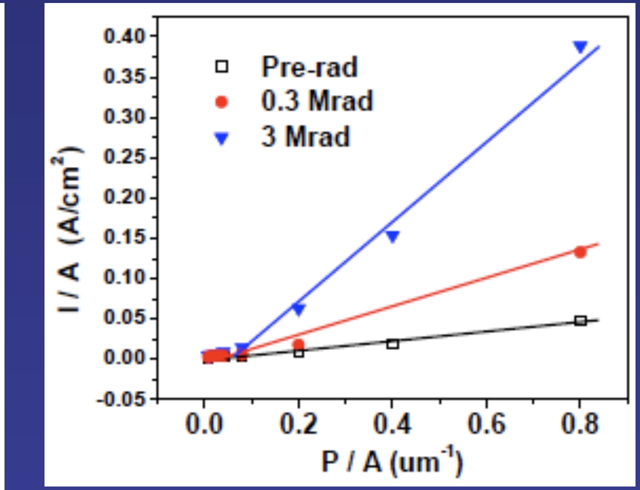
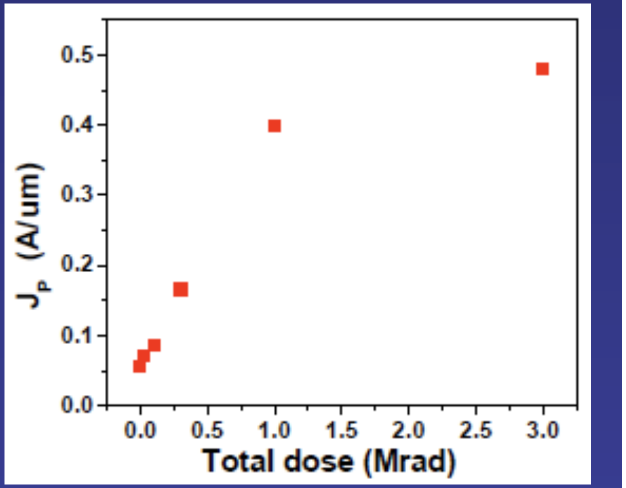
Mechanism behind increasing junction leakage with radiation







$$I/A = J_A + P/A \times J_P$$

- p^+-n junction leakage increases with total dose
- Increase due to increasing perimeter junction leakage with total dose
- Increasing parameter leakage current due to increase in density of interface traps close to the gate oxide-drain interface

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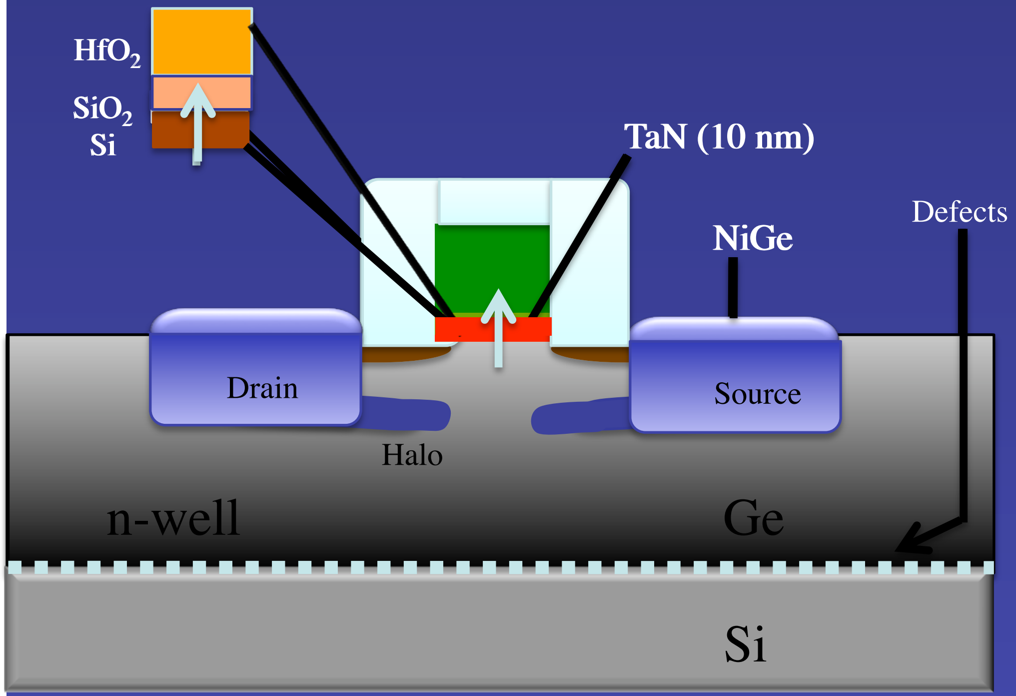
Effect of variation in halo doping and number of Si monolayer (ML)

- Variation in process effects total dose response
- All other process conditions similar



Wafer	Gate prebake and epilayer	Halo
D04	350 °C SiH_4; 5 Si Monolayers	As: 80keV, 5 × 10^{13} cm^{-2}
D09	500 °C SiH_4; 8 Si Monolayers	As: 80keV, 3.5 ×10^{13} cm^{-2}
D10	500 °C SiH_4; 8 Si Monolayers	As: 80keV, 6.5 × 10^{13} cm^{-2}

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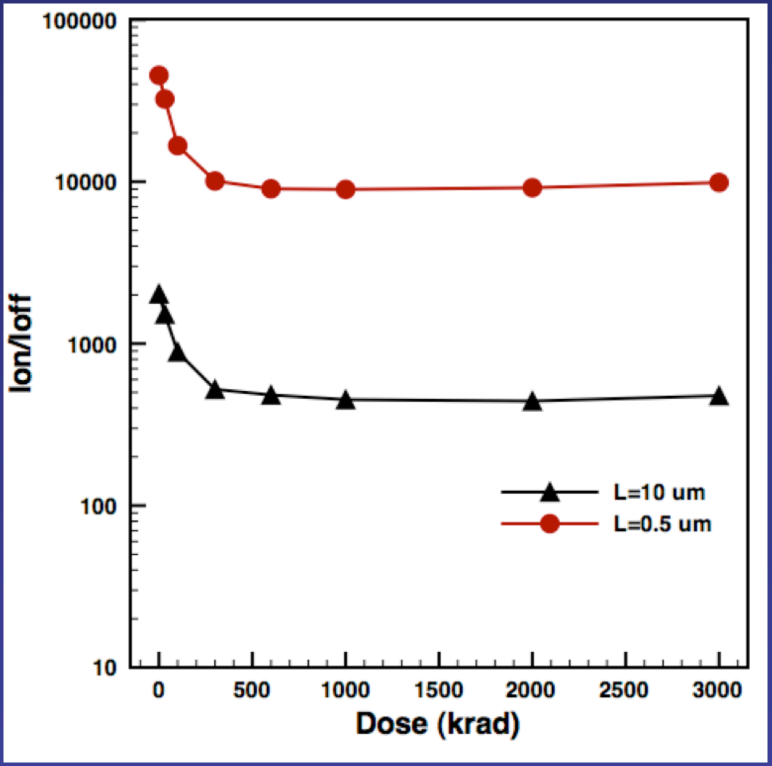
On/Off current ratio – L dependence



- Short Channel length (500 nm here) ⇒ greater prerad I_{on}/I_{off} than long channel length (10 µm here) device

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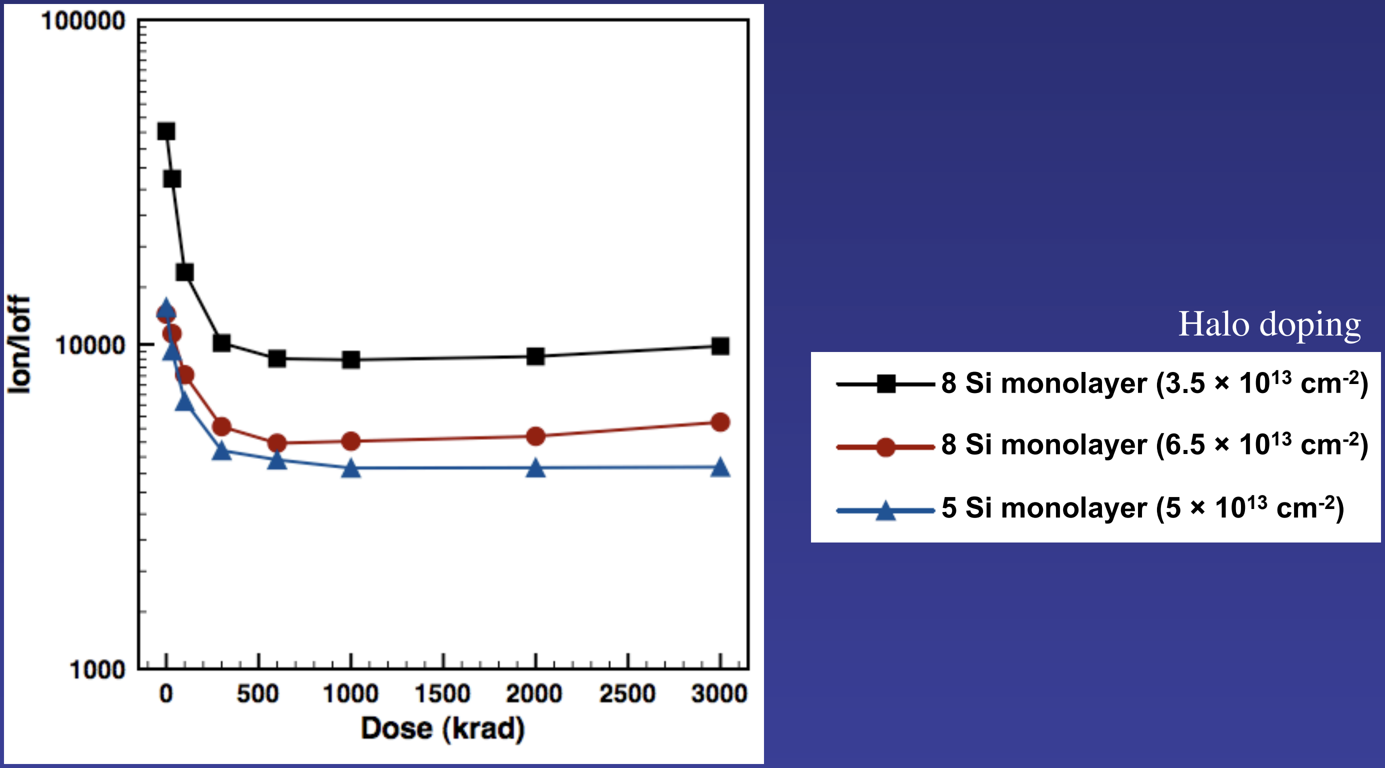
On/Off current ratio – process dependence



- Device with 8 Si ML and minimum halo doping density has best prerad I_{on}/I_{off} and maintains a higher value after radiation

- Device with 8 Si ML and higher halo doping density has better radiation response than D05 with 5 Si ML

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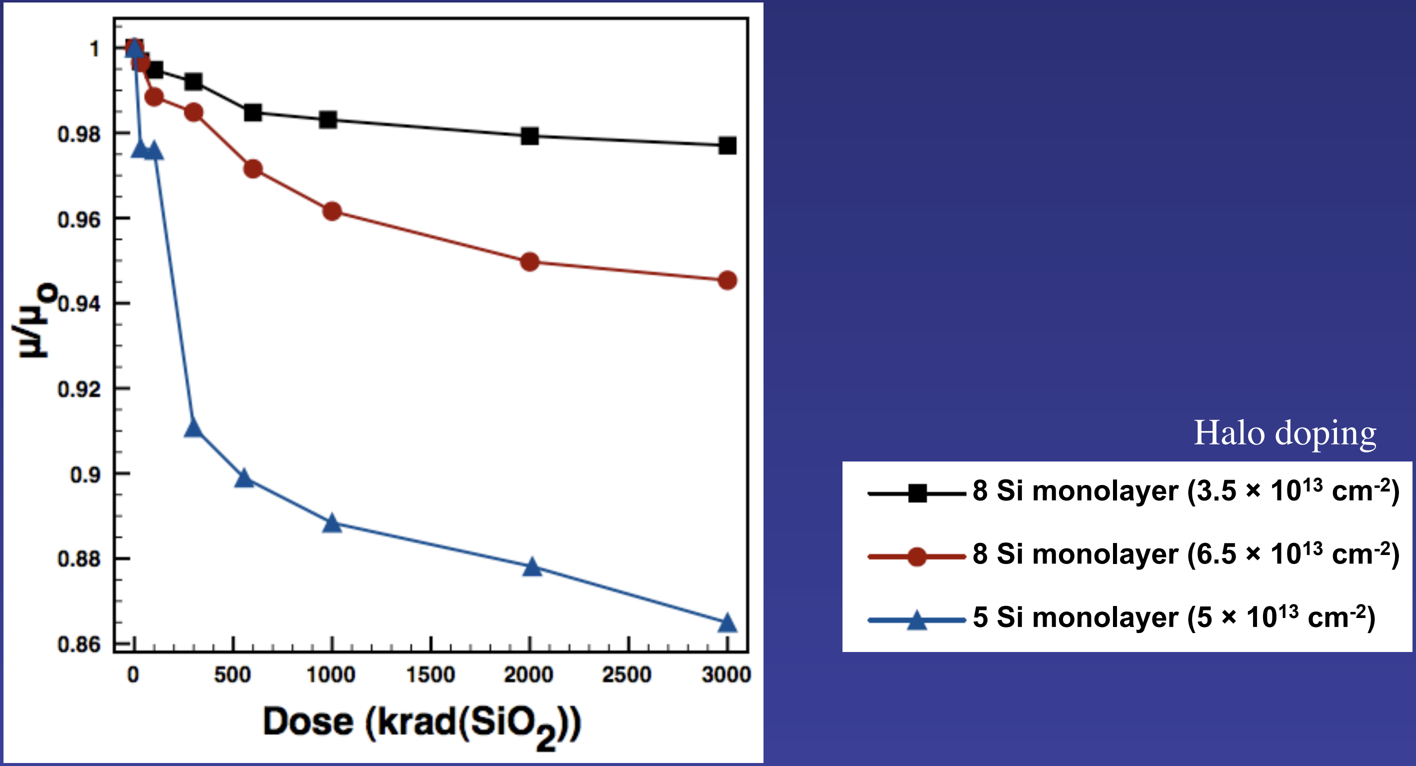
Mobility Comparison



- 8 Si ML devices do not show significant mobility degradation
- Device with 5 Si ML shows significant mobility degradation

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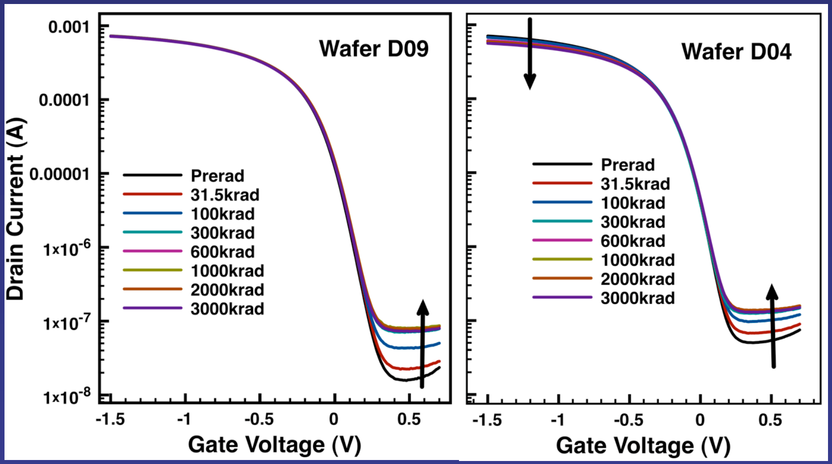
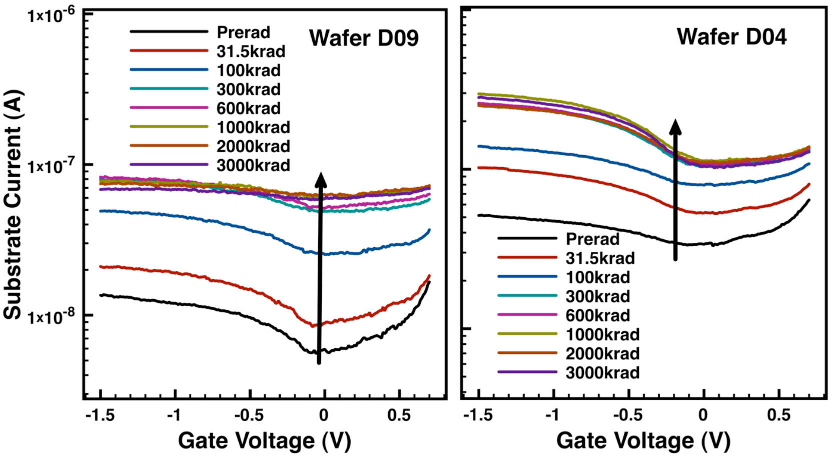
Increasing substrate current



8 Si ML 5 Si ML



8 Si ML 5 Si ML

- Increasing p^+-n junction leakage results in increased substrate current
- Substrate current for device D04 was more than D09 after radiation

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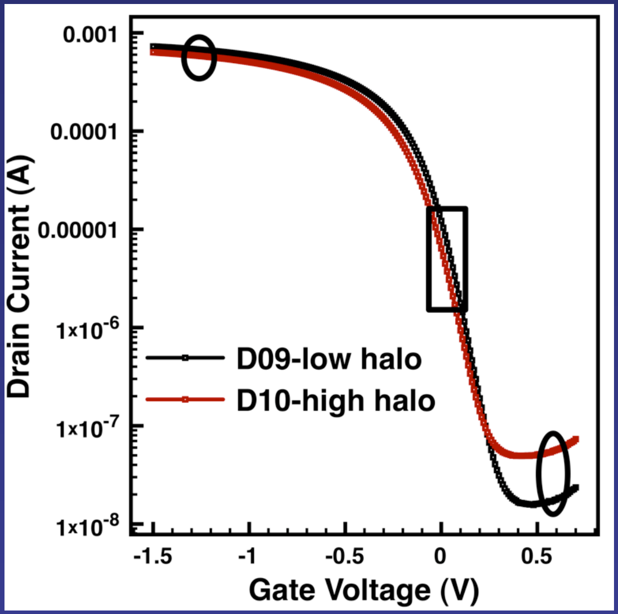
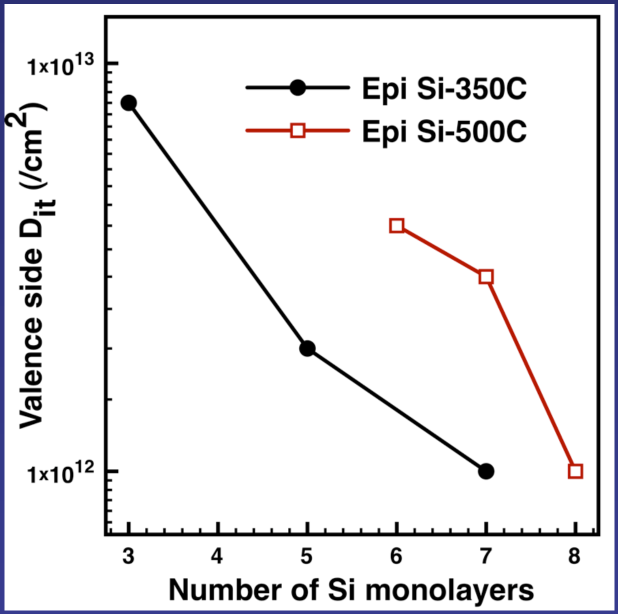
Mechanisms





- Lower halo doping → lower prerad off state current
- Off state current remains low for lower halo doping device with total dose radiation

- 8 Si ML device → lowest prerad interface trap density
- 8 monolayer device maintains comparatively lower interface trap density with total dose radiation

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Conclusions

- On-off current ratio decreases for Ge p-MOSFETs with total dose
- Process with minimum halo doping has maximum on -off current ratio
- Process with 8 Si monolayers has higher on-off current ratio than 5 monolayer devices
- Process with 5 Si monolayers shows the maximum mobility degradation with total dose

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