

epitaxy, which can be expensive and slow. However at this level of conjecture the tradeoffs between the two growth methods are extremely difficult to quantify.

Table 1. Summary of key parameters simulated and calculated from the two designs presented.

	<i>MSM Device</i>	<i>p-i-n Device</i>
Quantum Efficiency	39%	51%
Capacitance	<200 aF	<100 aF
Germanium Thickness	180 nm	450 nm
Minimum Carrier Transit Time	5 ps	9 ps
Maximum Voltage	2 V	4.5 V
Germanium Growth	GOI or Rapid Melt Growth	Direct Epitaxy on Silicon

Finally if one is interested in purely increasing the quantum efficiency of either device, metal loss will become an issue, especially since aluminum is rather strongly absorbing near 1500 nm. A less lossy material such as gold or silver can be used instead, which should increase the total efficiency slightly (>61%), but at the sacrifice of using solely CMOS compatible materials. Additionally, one could choose to use III-V material instead of germanium as the absorber which would also increase the quantum efficiency but at the cost of possible CMOS compatibility. However if III-V lasers were to be integrated into CMOS as was recently proposed [25], then it is not unreasonable to use the same highly absorbing material for the photodetector as well.

5. Conclusions

We have proposed both MSM and p-i-n device designs for sub-fF germanium photodiodes. Backed by theory and simulations, the MSM photodiode has 39% quantum efficiency with <200 aF capacitance, while the p-i-n photodiode has 51% quantum efficiency with <100 aF capacitance. Both devices utilize a single-mode cavity resonance and couple directly to a silicon waveguide, while using only CMOS compatible materials for the possibility of monolithic silicon photonics integration. When coupled with an appropriately designed receiver circuitry, these low-capacitance photodiodes should yield extremely sensitive photodetectors allowing for ultra-low energy photonic links.

Acknowledgments

We would like to acknowledge funding through the National Science Foundation Center for Energy Efficient Electronics Science (E3S) under NSF Award 0939514. National Science Foundation Center for Integrated Access Network (CIAN) under grant #EEC-0812072, Intel, the NSF Graduate Fellowship (DGE 1106400) and NDSEG Graduate Fellowship. The authors would also like to thank Amit Lakhani, Tae Joon Seok, and Michael Eggleston for very valuable discussions.