where C_n,V_n, I_n are the capacitance, voltage and current through minimum sized transistor at a given technology node, $I_{modulator}$ is the peak current through the modulator. We plot the maximum switching speed of the direct logic drive as a function of the drive current for the modulator in Fig. 6. Gate lengths, voltages and delays are taken from ITRS 2009, Table PIDS2: High Performance Logic Technology Requirements [32,33]. One can clearly see that at 1 mA current levels for the present modulator, switching speeds approaching 10 GHz can be realised using direct CMOS digital logic drives. The estimated scaled NMOSFET channel width for a 1 mA drive current is expected to be $G_{pmosfet} = G_{node} . I_{modulator} / I_{d,sat\,mode}$, assuming an $I_{d,sat}$ of 664 μA/μm at a 22 nm CMOS technology node [8]. This implies a drive transistor size of 1.5 μm which can scale down with current densities [8]. We note that the peak current in the device simulation shown in Fig. 5 is 3 mA, which corresponds to a scaled digital inverter cut-off bandwidth of 10 GHz in a 16 nm CMOS node. This reduction in footprint, driver energy, and complexity can enable seamless integration of nanophotonic with CMOS nano-electronics.

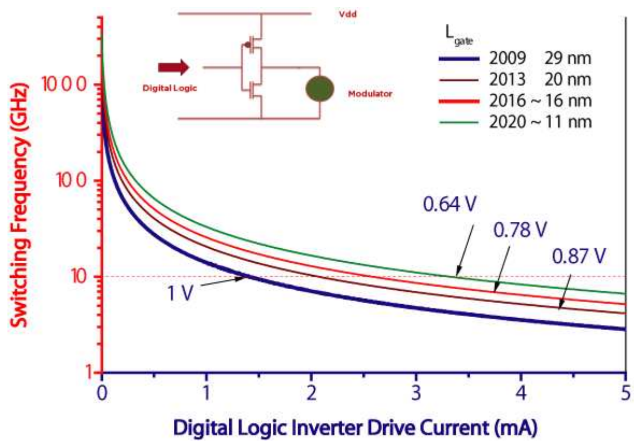

Fig. 6. Switching frequency of a single staged inverter driven directly with a digital logic level as a function of the drive current. The different colours indicate the switching frequency of the scaled digital layer inverter for various drive currents. A 10 GHz operation can be achieved for drive currents as large as 3 mA.

6. Conclusion

In conclusion, we demonstrate ultra-low drive voltage (150 mV) operation of carrier injection micro ring modulators in Gbit/s regime in an ultra low mode volume silicon micro-ring device. This low voltage driving scheme allows for direct digital logic driven modulators driven with micron sized transistors. To the best of our knowledge this is the smallest operating voltage (150 mV) for a GHz silicon modulator to date. The mode volume (2 μm^3, (~0.52 λ^3) & foot-print (~20 μm^2) of the modulator is also the smallest to date for a micro-ring silicon modulator. The ability to scale the voltages of nanophotonic modulators down to few 100 mV may enable compatibility with future low voltage nano-electronic technologies beyond 22 nm CMOS, enabling close integration of nanophotonics with nano-electronics.

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