The Device Research Conference: 1992-2017 and 2017-2042

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Starting with its 50th anniversary in 1992, I have seen 25 years of electron and photon device research at the DRC; let us look over this history and then guess at the future.

Before online conference proceedings, breaking results were announced at conferences and later published in journals. The IEDM and DRC, then as now, were the premiere conferences. We preferred the IEDM for Si and the DRC for III-V's. The cultures differed. The DRC has long fostered frank, rowdy discussion; if your result is controversial, expect to face energetic challenges, lubricated by beer, during the questions.

The 1980's and 1990's saw explosive progress in electronic and photonic devices. High-speed electronics saw the invention of modulation doping and AlGaAs/GaAs HEMTs. These, plus GaAs HBTs, progressed from 10GHz to several hundred GHz operation by the late 1990's. By the late 1980's, InP transistors had taken the lead for high-frequency work. By 2000-2017, work had narrowed to a few groups, and 1 THz was reached. GaAs found markets in radar, cell phones and Wi-Fi. In 1987, SiGe HBTs arrived. By 1992, these had reached 50 GHz; last year we saw 700GHz. Thus did the venerable Si bipolar close the gap with the III-V's, denying it most large markets. Now, it is CMOS which starves SiGe. Yet, 5G wireless now stampedes towards mm-wave: SiGe, InP, GaN and CMOS all fight again.

1992-2017 was the era of microwave power electronics and low-frequency kV switching, with the development first of 4H-SiC microwave FETs and the 1994 demonstration of GaN HEMTs. 2017 has seen 6.5W/mm at 94GHz, a formidable result.

By the 1990's, CMOS groups were attacking oxide scaling limits, first with nitrided oxides and then the high-K's. SOI was introduced, and all nature of surround-gate structures were announced. The finFET, a.k.a. the DELTA, proved the winner, at least for now.

Photonics beat Moores' law, with fiber links starting at Gigabits and ending at Terabits. Diode laser bandwidths shot up, then plateaued. MQW modulators took over, then also got stuck. Photonic integration and WDM chips stepped in, and kept up the progress in bit rate. Vertical-cavity lasers emerged for data links. Photonics is also lighting and seeing: the late 80's brought InAs/GaSb IR detectors, and the 90's GaN solid-state lighting. Goodbye incandescents and fluorescents.

Much work did not make it. Fallen aside are optical computing, resonant tunneling, metamaterials, electron waveguide devices, and quantum dot and single-electron transistors. I wasted my time on InP 40Gigabit fiber chip sets and on III-V MOS for VLSI. For plasmonics and 2D semiconductors, the jury is still out. I'm not qualified to judge the potential of quantum computing. It is easy to be blind to opportunity: complex photonic integration for WDM, silicon photonics, ferroFETs and tunnel FETs are things which I should have seen coming.

Where will technology stand in 2042? Predictions are hard. We overestimate short-term progress and underestimate long-term: technology is compound interest. Technical cynicism blinds us to opportunities. But, if we do not use theory to weigh new proposed research, then what is theory for?

What to do next? We could make a 10THz transistor, but above 1 THz the atmosphere is opaque; what is the use? Improving nm logic is profoundly hard: with so few atoms inside left to work with, it is hard to do clever things. 3D device integration seems the best path forward. Few-atom-scale memory is promising: can we controllably and repeatably move a few ions by an electric field ? Is neural computing the future ? Maybe not: my PC is poor at conversation, but in numerically solving electromagnetics, it beats me easily. Cellular biochemistry provides more powerful inspiration: a 1-µm prokaryotic cell is a complex Turing machine. Can we build $(1\text{-}\mu m)^3$ fluidic devices and control within them complex interlinked chemical reactions? Are nm biological sensing devices the next frontier ? Perhaps, but today's biochemical diagnostics use protein-specific binding, which provides tremendous selectivity. It seems likely that such binding must be part of a competitive electrical or optical biological sensor.

Pauling warned that to have good ideas you must have lots of ideas: most will be wrong. He also advised young scientists to politely ignore older ones, and instead think for themselves.