Q1. In terms of future 6G communication, would most of the data be transmitted/received on millimeter-wave or <6GHz?

Answer: Today, lots of attention is devoted to C-band (between 4 and 8 GHz, but specifically at 3.7-3.98GHz carrier frequency). In the near future the sub-6GHz frequency range will carry most of the traffic. But as time passes (possibly in 2-4 years), inevitably, larger traffic will move to mmWave.

More data throughput needs broader spectrum. We need to find 1-1.5GHz additional spectrum in order to support the growth of wireless data traffic. This spectrum is only available at higher frequencies, with deployments today in the 30-50GHz range and research in the 140GHz and even 200GHz range.

Due to cost, efficiency and propagation, more attention should be placed on how to get commercial access to FR3, 8-20GHz. This will require significant investment and joint work between researchers (interference), commercial companies, regulators and standards bodies.

BTW, in the Verizon earnings call recently, they emphasized the strong growth of mmWave data traffic.

Q2. “GaN for Opto(micro-LED) is progressing to 8”, Mass production expected in 2 years. Maybe RF GaAs, (or InP) can also enjoy the 8" benefit and with finer process node to compete with SiGe for higher switching frequency?”

Answer: The integration of bipolar technologies, whether as SiGe, GaN, GaAs or InP with CMOS is key to the future of both RF and Silicon Photonics. While SiGe uses monolithic integration with Si or SOI, III-V materials will require 3D integration using wafer to wafer or collective die to wafer bonding. RF GaN on Silicon substrates is probably the leading technology for this approach, and will share commonality with GaAs for both power devices as well as micro LED.

Q3a. As we can see that all communications technologies are based on the use cases that intertwine and directly proportional to device computing abilities. What are experts' outlook if Quantum computing is easily accessible and is clubbed with current binary system of enterprise software and systems??

Q3b. Where does quantum / cryogenic computing fits in this discussion?

Answer: Quantum computing with its anticipated crypto power is expected to cause problems for secure communications.

Q4. Marla mentioned about the circuit and board level imaging, scanned probing, etc. or if we may call it "physical assurance" for heterogeneous integration and electronics. They become even more important in a 3D structure. This entails to extremely large size imaging and data collection and AI algorithm development to make the process fully automated. What are the current programs NIST or government have now in this area or plan to have to get researchers, academia involved? And do you think that the level of investment is enough?

Answer: You can learn more about R&D on measurements for 3D device characterization @ https://www.nist.gov/programs-projects/advanced-high-frequency-devices.

For information about "physical assurance" for 5G devices: https://www.nist.gov/programs-projects/measurement-based-approach-5g-supply-chain-security"

Another useful reference is 2021 IEEE Symposium on Heterogeneous Integration: https://r6.ieee.org/scv-eps/?p=2416