3D Heterogeneous Integration (3DHI): Revolutionizing RF Systems

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ABSTRACT

To perform increasingly diverse missions in increasingly crowded electromagnetic (EM) environments, future sensor and communication systems will require increased bandwidth, sensitivity and enhanced functionality per unit area. This in turn is driving systems toward higher operating frequencies, which more easily support larger channel bandwidths and higher resolution. For example, today's cellular networks (i.e., cellular networks based on 5G) operate at 6 GHz and below with limited deployment for 5G at millimeter wave frequencies (from 24.25 GHz to 52.60 GHz). 6G is anticipated to push to even higher millimeter wave frequencies in pursuit of larger channel bandwidths and higher channel capacities. Millimeter wave arrays also enable high resolution imaging, such as a new class of automotive radar for autonomous vehicles for imaging through fog [1].

Millimeter wave arrays can be implemented using either silicon-based (e.g., CMOS, SiGe) RF integrated circuits (ICs) or III-V compound semiconductor (e.g., GaAs, GaN, InP) MMICs. Each approach has advantages but also limitations. For example, silicon-based circuits use dense, planar, multi-layer back end of line (BEOL) interconnects and integration technologies that enable highly compact and functionally dense chips and multi-chip assemblies. Silicon RF IC and integration technology have been used to successfully demonstrate phased arrays that operate through D-band (140 GHz) [2], however, these arrays have very low efficiency, which limits their utility to support operation in power constrained applications. Through significant investment, III-V transistor technologies (e.g., InP, GaN) provide significant performance (e.g., gain, power, noise, efficiency) advantages over silicon-based transistors, with operation at G-band and THz frequencies demonstrated. However, III-V-based technologies do not have the integration density necessary to realize compact millimeter wave arrays. The ideal solution is 3D heterogeneous integration which combines the performance advantages of III-V transistors with the integration density of silicon technology. This talk will present an overview of programs that are developing Si-like fabrication and integration solutions to enable 3D heterogeneous integration of high-performance compound semiconductor (GaN, InP) transmit and receive amplifiers with silicon and non-silicon components (e.g., Si beamformer ICs and quartz antenna layers) to create efficient millimeter wave arrays. These programs are laying the foundation for next generation millimeter arrays and massive MIMO systems.

[1] Savage, N., "Autonomous cars drive terahertz research," SPIE Technology News, March 1, 2021. Available: https://spie.org/news/photonics-focus/marapr-2021/autonomous-cars-drive-terahertz-research

[2] A. Ahmed.et al., " 140 GHz Scalable On-Grid 8x8-Element Transmit-Receive Phased Array with Up/Down Converters and 64QAM/24 Gbps Data Rates" 2023 IEEE Radio Frequency Integrated Circuits Symposium (RFIC), 2023.