VLSI Photonics: Visions, Challenges and Progresses

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Abstract

This lecture presents a comprehensive review and overview on the cutting-edge frontier science and engineering of micro/nano-photonic integration for VLSI photonic application. It discusses on the theory, design, fabrication, and integration of micro/nano-photonic devices, circuits, chips, and networks in the form of "VLSI photonic integrated circuits"(VLSI-PICs) and "optical micro/nano-networks (O-MNNs)" of generic and application-specific nature on a platform that we call "optical printed circuit boards" (O-PCBs). These systems are designed to be compact, intelligent, high-speed, lightweight, environmentally friendly, low-powered, and low-cost as applicable for datacom, telecom, transportation, aero-space, avionics, bio/medical, sensor, and environmental systems. The O-PCBs, VLSI-PICs and O-MNNs process optical signals through optical wires whereas the traditional E-PCBs, VLSI-ICs, and electrical networks process electrical signals through electrical wires. The VLSI photonic systems are designed to overcome the limitations of the VLSI electrical systems and are also designed to integrate convergent IT/BT/NT micro/nano-devices, circuits, and chips for broad based applications and usages. The new optical systems consist of 2-dimensional planar arrays of optical wires, circuits and devices of micro/nano-scale to perform the functions of sensing, storing, transporting, processing, switching, routing and distributing optical signals on flat modular boards or substrates. The integrated optical components include micro/nano-scale light sources, waveguides, detectors, switches, modulators, sensors, directional couplers, multi-mode interference devices, AWGs, wavelength filters, micro-ring resonator devices, photonic crystal devices, plasmonic devices, and quantum devices, made of polymer, silicon and other semiconductor materials. Some molecular devices are also considered. We discuss scientific and technological issues, challenges, and progresses regarding the miniaturization, interconnection and integration of micro/nanoscale photonic devices, circuits, and networks leading to ultra-small and very large scale integration and discuss their potential applications mentioned above. The issues include the compatibility issues between micro/nano-devices such as materials mismatch, size mismatch, mode mismatch, optical mismatch, mechanical/thermal mismatch and the nano-optical effects such as micro-cavity effects, non-linear effects, and quantum optical effects in nano-scale devices. Scaling rules for the miniaturization and integration of the micro/nano-photonic

systems will also be discussed in comparison with those of the micro/nano-electronic systems. New physics, visions, issues and challenges of the optical micro/nano-optical circuits, networks and systems will be discussed along with the historical perspectives of the electrical technology. Recent progresses and examples will be presented along with the future outlook.