Nanophotonics for information systems

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Optics has the potential to solve some of the most exing problems in computing hardware. It promises crosstalk-free interconnects with essentially unlimited bandwidth, long-distance data transmission without skew and without power- and time-consuming regeneration, miniaturization, parallelism, and efficient implementation of important algorithms such as Fourier transforms. Yet, optical computing and processing in space and time has so far failed to move out of the lab. The free-space and guided-wave devices are costly, bulky, and fragile in their alignment. They are also difficult to integrate with electronic systems, both in terms of the fabrication process and in terms of delivery and retrieval of the massive volumes of data the optical elements can process. Moreover, there exist applications that rely on our ability in interfacing optical devices and systems with other signal modalities such as for example biological and biochemical processes. These applications led us recently to establishing a new research area that we call optofluidics, where fluids are used to create adaptive optical elements, control them, and establish efficient interfaces with biochemical systems.

Things may be changing, however. More recent work emphasizes the construction of optical subsystems directly on-chip, with the same lithographic tools as the surrounding electronics. This has been made possible by the advances in these tools, which can now create features significantly smaller than the optical wavelength; experts predict lithographic resolution as fine as 16 nm by year 2020. Arranged in a regular pattern, subwavelength features act as a metamaterial whose optical properties are controlled by the density and geometry of the pattern and its constituents. Lenses, polarizers, chromatic dispersers, diffraction gratings, and other optical processing devices can now be implemented on-chip using metamaterials wherever natural materials with similar properties either do not exist, or (more frequently) would not be compatible with lithographic fabrication.

To advance this technology, investigations of nanostructures and their interaction with electromagnetic field are critical. Engineers also need appropriate modeling and design tools, new fabrication recipes, and test instruments capable of characterizing on-chip components. The design of integrated photonic systems is a challenging task as it not only involves the accurate solution of electromagnetic equations, but also the need to incorporate the material and quantum physics equations to enable the investigation and analysis of near field interactions. These studies need to be integrated with device fabrication and characterization to verify device concepts and optimize device designs. In this talk, we discuss some of the CMOS-compatible SOI metamaterials and devices recently demonstrated. These include graded-index lenses, birefringent elements that utilize a combination of geometry and material properties to separate light into orthogonal polarizations, frequency-selective resonators and Bragg gratings, and metal-dielectric nanostructures that can achieve extremely tight field confinement. Characterization tools, including heterodyne near-field optical microscope, will also be discussed. This microscope uses a fiber probe tapered to 100 nm diameter and brought close enough to the nanostructure under test to pick up its evanescent electromagnetic fields. Subsequent heterodyne detection permits simultaneous measurement of both amplitude and phase of the evanescent fields, while also providing an amplification to boost the weak signal. The mapping of evanescent fields has proven to be a powerful aid in understanding the performance of nano-optical elements.