**INTRODUCTION**

**ELECTRONIC INTEGRATED CIRCUITS (ICs) versus PHOTONIC INTEGRATED CIRCUITS (PICs)**

- QDs exhibit the requirement of a single active device - the transistor - for the computing and processing functions of the circuit.
- PICs are structurally complex circuits that can accommodate multiple photon devices to perform three fundamental photonic functions: (i) the emission and confinement of light; (ii) the guiding and coupling of light; and in the detection of light (Xu et al., 2005).
- Traditional lateral integration of these photonic devices on a single chip requires larger footprints. The vertical integration scheme would facilitate the development of more compact PICs for commercialization.
- PICs rely on the movement of photons, which, if harnessed, could enable the creation of affordable (altruist), high-capacity telecom. devices and networks (Kaiser et al., 2002).

**MATERIAL SYSTEMS**

- Polymeric materials have replaced traditional semiconductors as material systems for creating PICs because (i) the monomers, functional groups, and other structural elements can be altered and (ii) they possess an inherently flexible structure (Huang et al., 2004).
- Quantum dots (QDs) (2-10 nm) or semiconductor nanocrystals, are direct bandgap semiconductors whose intrinsic and discrete luminescent properties result from quantum-size confinement. QDs have discrete energy levels leading to discrete emission wavelengths.
- QDs are highly tunable since the size of the QDs determines the bandgap. The wavelength and intensity of the light emitted, along with certain electrical and magnetic properties, can thus be regulated (Parken, 2000).
- QDs exhibit rapid recovery times, retain their emission properties when subjected to mechanical stresses, are highly photostable, and do not wash off since spontaneous emission is not a phenomenon of whispering gallery modes (WGMs).
- These PICs would have a breadth of applications as biosensors in biomedical research and as ultrafast and high-performance PICs in telecommunications and other technologies requiring ultrafast (terabit/sec) processing devices (Kaiser R. 2002).
- These PICs lacked an intermediate planarizing layer, which is the current focus of our experimentation.
- The picric solution in this project can be used to fabricate single-wall carbon nanotubes (SWCNTs) and multiwalled carbon nanotubes (MWCNTs) using a top-down approach.

**MICROFABRICATION TECHNIQUES**

**ELECTRON BEAM LITHOGRAPHY**

- Electron beam (FIB)-lithography is the most accurate technique for fabricating PICs. In this process, a photolithography (light sensitive polymer) is selectively etched and patterned with structures using a beam of electrons.
- The E-beam fabrication of PICs has limited commercial value due to its limited throughput (PICs can only be produced one at a time) and the price tag of electron beam writers.

**PHOTOLITHOGRAPHY**

- Photolithography requires the fabrication of a mask (UV transparent material, such as glass) onto which chromium is patterned. The chromism or pattern is transferred to the underlying photoresist.
- Photolithography successfully mass produced nearly 3 billion transistors per second in the US in the year 2007 (Whitesides et al. 2007). However, the technique depends on an expensive and difficult to modify photolithography equipment.

**SOFT LITHOGRAPHY**

- Soft lithography requires minimal equipment and time to fabricate PICs. Since its development in the early 1990s, several techniques, such as microcontact printing and micromolding, have emerged.
- A master is fabricated, which is used to create a polydimethylsiloxane (PDMS) stamp. PDMS is a viscous and elastomeric polymer with a high molecular weight. When it is cast and cured on the basis of a template, it produces a negative stamp that can be used to create exact replicas at a high throughput.
- This technique has several shortcomings: (i) fabrication of a mask is dependent on e-beam lithography and photolithography; (ii) inability to fabricate three-dimensional, vertically integrated PICs; (iii) inadequate low adhesive force of 23 dynes, PDMS tends to adhere to the substrate; and (iv) the PDMS stamp can deform easily during the stamping process (Whiteides et al., 2007).
- The limiting factor size of soft lithography is a controversial issue; some research groups claim that a resolution of 10nm is achievable while others claim the structures would be too low quality to be effective (Huang et al., 2004).

**TOP-DOWN versus BOTTOM-UP APPROACH**

- Most PICs are currently realized using the top-down approach, which starts with the fabrication of a large device from which individual devices are carved. PICs fabricated using this approach include microchips, PICs on the complementary metal–oxide–semiconductor (CMOS) platform, and Asymmetric Twin Guide (ATG) based PICs.
- The top-down approach is limited by its high cost and the time consumed to fabricate PICs (Whiteides et al., 2007). The PICs created also have large footprints, which prevents commercialization.
- The approach employed in this research builds devices from the bottom-up, creating smaller sized and low cost PICs with smaller footprints. Although the bottom-up approach has been studied before, no one has attempted to create PICs using this approach to produce multilayered structures with interlayer integration.

**HYPOTHESIS:**

Adoption of the bottom-up approach along with innovative material systems and monolithic integration of fundamental photonic functions, will make the realization of commercially accessible 3D PICs possible.

**RESULTS (cont.)**

**VERTICALLY INTEGRATED PIC (cont.)**

- The prototype top layer had CdSe QDs that did not wash off since spontaneous emission was exhibited on the entire top layer.
- After switching to CdSe QD solutions in hexane, a prototype PIC with a passive bottom layer, an active upper layer, and no intermediate planarizing layer was successfully fabricated.
- During a photoluminescence test, enhanced emission from the CdSe QDs was not exhibited.

**TEFLON**

- Various Teflon AF2400 solutions were tested. Each solution had Teflon dissolved in 3-MC (FC-40).
- An 11% Teflon AF2400 by weight solution appeared to be solid when completely liquefied.
- A 1% Teflon by weight solution yielded a homogenous solution that could be spread evenly. Observed under an atomic force microscope and surface profilometer, the Teflon layer was found to be too thin (Figure 13).
- Teflon solutions of higher concentration are being prepared and tested to obtain the desired thickness.

**DISCUSSION**

- Our first approach was to create laterally integrated PICs consisting of microdisks and waveguides with lateral separation by utilizing soft lithography. We encountered resolution issues with the replica PICs. The 200 nm grooves in the disk pattern were not well defined (Fig 7). A
- The resolution and material system issues of soft lithography must be resolved to commercially fabricate smaller scale PICs with precision and accuracy before the technique can be effectively used.
- After attempting soft lithography, we determined that the bottom-up approach employing photolithography would be used to realize three dimensional PICs.
- Aligned, multilayered circuits with active and passive devices had been successfully fabricated (Fig 9, 10, 11). However, these PICs lacked an intermediate planarizing layer, which is the current focus of our experimentation.
- The viscosity of the Teflon solution has not yet been optimized for the thickness our PICs require; this issue is currently being resolved.
- Also, the QDs embedded in the SU-8 matrix did not wash off in the unexposed areas when stripped in SU-8 developer. Preliminary results indicated that this may be self-organization of QDs due to solvent separation. CdSe dots dissolved in hexane were used as an alternative, but the same aggregation issues occurred. The slow diffusion process recommended by researchers at the University of California to add the QDs to the SU-8 was also used, but the results did not differ (Pang et al., 2005).
- An active and passive layered PIC analyzed under the AFM’s CCD camera did not exhibit any enhanced emission, which is abnormal since QDs retain their luminous properties after being conjugated (Chan W., et al. 1998).
- Three dimensional monolithic PIC with efficient coupling will soon be fabricated, facilitating the realization of multifaceted, compact, and commercially available optical devices.
- These PICs would have a breadth of applications as bio-sensors in biomedical research and as ultrafast and high performance PICs in telecommunications and other technologies requiring ultrafast (terabit/sec) processing devices (Kaiser R. 2002).
- Moore’s Law states that the number of transistors on an IC must double every 18 months. The integration of PICs and ICs will bolster the opto-electronics field and facilitate the creation of transistors and other devices capable of processing at terahertz speed instead of the conventional gigahertz speed of ICs.

**REFERENCES**