Injection of 2D Electron Gas into a Quantum-Dot Organic Light-Emitting Diode Structure on Silicon Substrate

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Utilization of quantum dots (QDs) as luminophores in organic light emitting diodes (OLEDs) has proven to be an effective way to produce a highly-efficient and cost-effective LED structure. Integrating a light emitting function on a silicon platform is expected to complement silicon electronics advancing Si photonics. In this paper, we present a unique OLED structure utilizing silicon as substrate as well as cathode electrode. In this device structure, the effective junction area is defined by a lithographically patterned oxide layer on Si substrate, allowing the opportunity to scale the LED dimension down to a nanometer range.

We observed an interesting carrier injection mechanism originating from the two-dimensional electron gas (2DEG) system at the interface between the oxide and the semiconductor. The Coulombic repulsion in the 2DEG reduces the energy barrier for electron emission[1,2], leading to a high injection current density under lower bias voltage. This injection mechanism allows one dimensional emission in the proposed LED structure.

To demonstrate 2DEG injection, we have fabricated QD-OLED structure with widely varying junction dimensions (100nm to 100μm) and geometry on silicon substrate by employing a micro-to-nanoscale lithographic technique (photo-, electron beam, or focused ion-beam lithography) and plasma etching of field oxide. The current-versus-voltage (I-V) measurement and emission brightness indicates that the 2DEG emission at the channel edge is the dominant mechanism of carrier injection compared to the broad area injection from silicon. Moreover, we found that compared to the conventional bottom emitting OLED built on ITO substrate, the 2DEG emission region is less affected by environmental, aging and thermal degradation, process non-uniformity and fabrication environment due to its quasi one dimensional injection nature at low bias voltage. By utilizing the nanoscale lithographic fabrication process, we plan to extend our work to develop single quantum dot light emitting devices on silicon substrate.

[1] S. Srisonphan,Y. S. Jung, and H. K. Kim, Nature Nanotechnology 7, 504–508 (2012).
[2] M. Kim and H. K. Kim, J. Appl. Phys. 118, 104504 (2015).

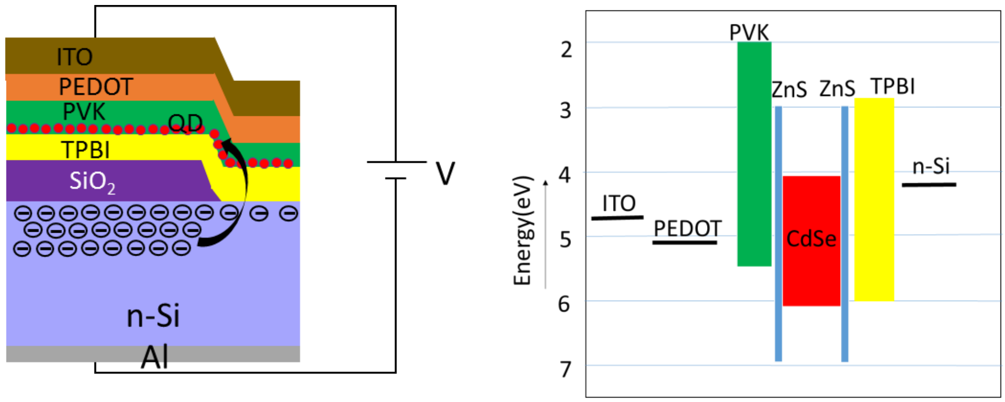

Figure 1: (left) OLED device cross-section showing 2DEG emission mechanism at the Si/SiO_2 interface under positive bias; (right) Corresponding energy band diagram of the device.

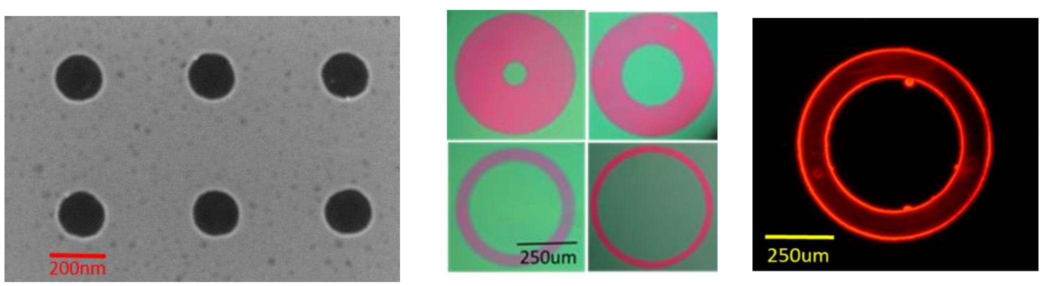

Figure 2: (left) SEM image of a nano-hole array patterned by electron beam lithography on SiO_2(23 nm)/Si substrate; (middle) Optical micrograph of ring patterned OLED devices of various ring widths; (right) Emission photo of ring patterned QD-OLED revealing brighter edge emission induced by 2DEG injection.

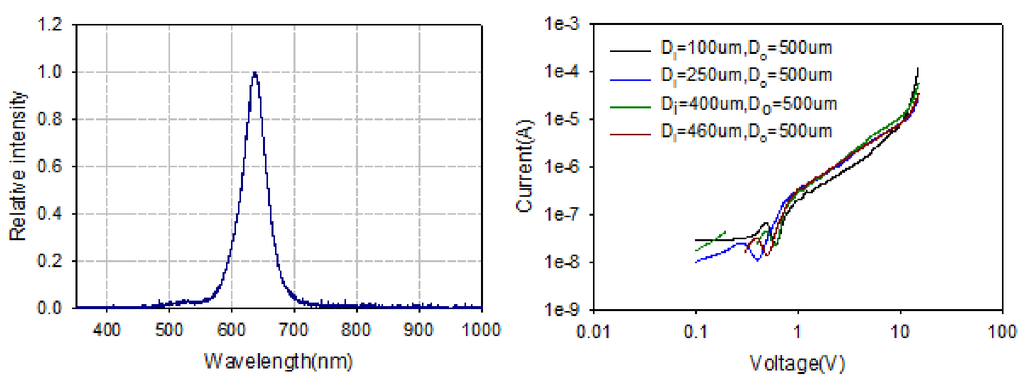

Figure 3: (left) Electroluminescence spectrum of OLED at 10 V bias; (right) I-V measurement data for ring patterned samples shown in Figure 2 (middle).