Quantum Dot Light Emitters

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Abstract

Quantum confinement effects allow radiative recombination of holes and electrons in silicon nanoparticles (NP), also referred to as quantum dots (QD). This is an area of considerable interest as QDs have the potential for high efficiency, and have the ability to tune the emission wavelength with the QD size. Currently, devices use organic polymers to inject holes and electrons onto the QDs, where 1-2% radiatively recombine. Inorganic materials are generally deposited at elevated temperature. The low thermal stability of QDs result in a belief that they are incompatible with inorganics. The objective of the current approach is to demonstrate how a layer of QDs behaves when trapped between two inorganic materials. To test the photoluminescence (PL), we deposited QDs on silicon nitride and used atomic layer deposition (ALD) to grow a thin layer of hafnium oxide (HfO_2) at very low temperature. The PL was measured after deposition of QDs and HfO_2. Results show no degradation in PL intensity. For electroluminescence (EL) measurements, we used a structure of ITO-ZnO-QDs-AlN-Pt. The silicon NPs used were generated by decomposition of silane in plasma and were directly deposited onto the substrates. The devices were created by ALD deposition of zinc oxide (ZnO) on an indium tin oxide (ITO) covered glass slide and sputtering of the aluminium nitride (AlN) onto the QD-ZnO-ITO layers.

Introduction

We can exploit the quantum confinement effects in quantum dots (QDs) to cause photoluminescence (PL) and electroluminescence (EL). Current direct-gap inorganic light emitting diode (LED) technology is efficient but expensive. The organic LEDs used today have reliability problems as well as poor color depth. By using QDs as the electroluminescent element, we can tune the emission wavelength and potentially create high efficiency reliable EL devices. Presently, to conduct electrons and holes to the QDs, organic polymers are used as the electron and hole conducting layers. The use of these materials presents many of the same stability problems seen in organic light emitters. We will attempt to use inorganic materials instead.

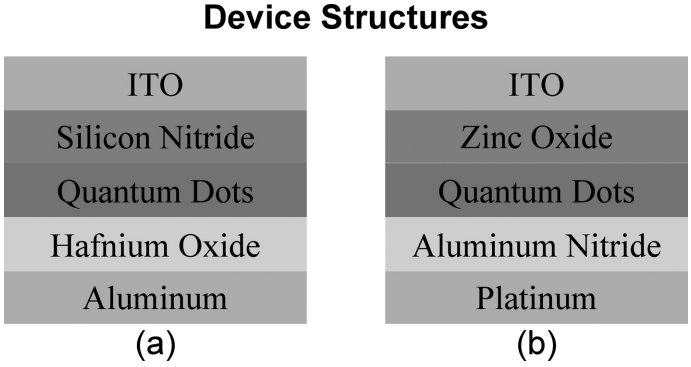

Figure 1

Experimental Procedure

The focus of this project was two-fold. First, we must determine if the intensity of the PL of QDs is reduced when sandwiched between inorganic materials. This will allow us to determine whether the quantum confinement effects or the crystalline structure of the QDs are damaged. Second, we must find if electroluminescent devices can be created using only inorganic materials.

The device to test the PL was fabricated on a glass slide that was covered with ITO. The structure, as shown in Figure 1a, was plasma enhanced chemical vapor deposition (PECVD) Si_3N_4, a layer of QDs, and ALD HfO_2. The Si_3N_4 layers were between 60Å and 90Å, grown at a rate of 75Å/min. The QDs were deposited by placing the samples in the exhaust stream of the plasma where the QDs were formed. The samples were placed in the exhaust stream for 30s, 45s, 1 min,2 min, 3 min, 4 min and 6 min. Following QD deposition, 60Å of HfO_2 were grown on the samples by ALD at 130°C using trimethyl aluminum and water. The PL was tested after both the QD deposition and the ALD.

To test the EL, the device shown in Figure 1b was fabricated. 70Å of ZnO was deposited at 250°C on the ITO covered glass slide using ALD. The QDs were deposited in a similar fashion as the first set of devices. The layer of AlN was sputtered for 1 min using an Al target and N_2 in the environment. Platinum electrodes were then sputtered on top of the AlN.

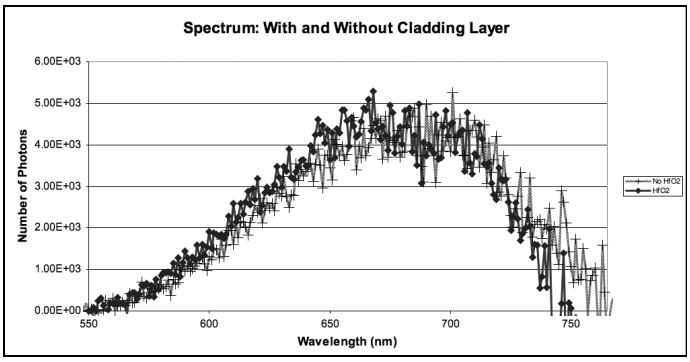

Figure 2

Results and Conclusions

The spectrums of the Si_3N_4/HfO_2 devices, shown in Figure 2, indicate that there was no noticeable change in intensity of the PL after HfO_2 deposition. The tests were run under the same conditions, so that the magnitudes of the spectrums were comparable. This indicates that the crystalline structure and the quantum confinement effects of the QDs were intact. Thus, ALD growth methods can now be used to create novel device structures.

The ZnO/AlN devices should have behaved as a diode due to the band alignment. However, the I-V curves in Figure 3 show that the behavior was ohmic. We believe there were pinholes in the thin sputtered films, causing all the current to flow through only one material and to be localized near the pinholes. This also would explain why no EL was observed. None of the current went through the QDs. When a constant voltage was applied to the devices and the devices were excited by UV light, PL was clearly visible, but the current flowing through the device did not appreciably change.

These results do not rule out the possibility that inorganic layers may be used as electron and hole transport layers. However, the films that were grown over the QD layer were only characterized using ellipsometry and profilometry on test wafers. This does not tell us what types of films were actually being grown on the QDs. Therefore, the results indicated that the structure of the devices were not as expected. Due to the extreme uniformity of ALD layers, we suspect that the pinholes were in the sputtered films, although this has yet to be proven.

Future Work

Since the quality of the films appeared to be a problem, careful study of the nucleation and growth of films on quantum dots needs to be pursued. The layer of QDs should also be characterized, as it would allow us to determine what type of surface we are depositing the materials onto. There should also be tests on control substrates so we can determine what thickness of materials are necessary to reliably gives us diode characteristics.

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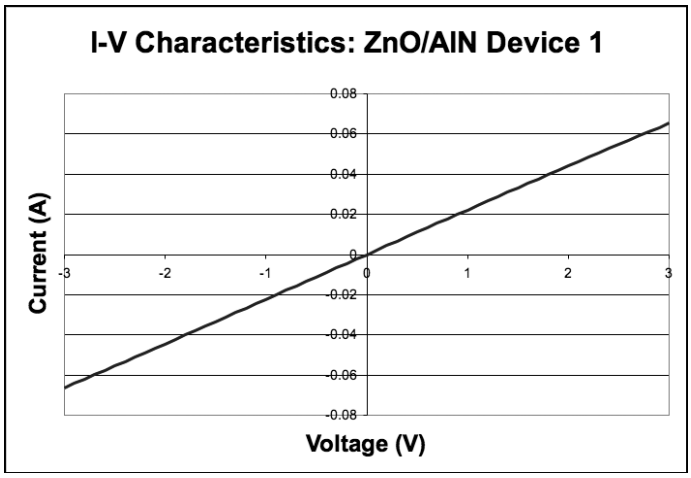

Figure 3