Investigation of Atomic Layer Deposition for Distributed Bragg Reflectors

Jonathan Chandonait

Nanoscale Engineering, Colleges of Nanoscale Science and Engineering, SUNY Polytechnic Institute

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CNF REU Principal Investigator: Prof. Huili (Grace) Xing, Department of Electrical and Computer Engineering, Department of Materials Science and Engineering, Cornell University

CNF REU Mentor: Shyam Bharadwaj, Department of Electrical and Computer Engineering, Cornell University

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Contact: jchandonait@sunypoly.edu, grace.xing@cornell.edu, sb2347@cornell.edu

Website: http://www.cnf.cornell.edu/cnf_2017reu.html

Abstract:

Distributed Bragg reflectors (DBRs) have been proposed as a method for increasing the external quantum efficiency (EQE) of light emitting diodes (LEDs) in the UV-C wavelength range (200-270 nm). The DBR essentially works as a mirror, collecting photons emitted in the active region of the device and reflecting them to an area where they can be extracted from the device. DBRs can be fabricated using molecular beam epitaxy (MBE) using alternating layers of AlGaN with varied composition [1]. However, atomic layer deposition (ALD) provides an alternative with several possible advantages. ALD allows the growth of dielectric films which may improve the effectiveness of these DBRs [2]. ALD also allows easier access to a much broader range of materials thanks to the flexibility of the tools. Here, we discuss preliminary efforts to evaluate ALD as a method for the fabrication of DBRs.

Summary of Research:

In current UV-C LEDs, the external quantum efficiency, or the ratio of generated photons that leave the device to electrons passing through, is currently low due to absorption losses and total internal reflection within the device. Distributed Bragg reflectors have been proposed to mitigate these issues. By using periodic quarter wavelength layers with a high refractive contrast, a mirror stack can be created with very high reflectance (Figure 1). Therefore, a large majority of the photons that reach the mirror stack will be reflected out of the device, improving the EQE of the device.

Currently there is little variety in the fabrication of DBRs for DUV LEDs. Most use MBE to grow varying compositions of AlGaN, although recently more groups have started to explore more possibilities. There are a few novel methods to change the formula, such as incorporating boron, but choices of materials are limited with MBE. Using ALD broadens the choice of materials, allowing us to take advantage of high-index contrast dielectrics, which could possibly increase the overall reflectance over a standard DBR.

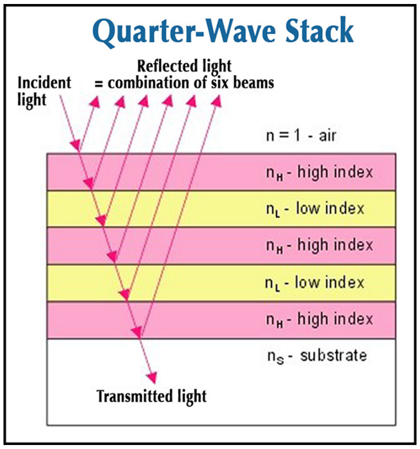

Figure 1: Shows the structure of a DBR and behavior of the photons that enter [3].

Our goal was to investigate some of the advantages and obstacles involved with using ALD as a method for fabricating DBRs. In the future, the goal is to develop a dielectric mirror stack fabricated by ALD with a reflectance of > 99.9% in order to prove the viability of the method.

Results and Conclusions:

Three different ALD materials were examined for surface roughness. AFM was used to characterize the surface roughness of the deposition for each material. All three depositions were carried out using 300°C plasma ALD.

Ta_2O_5 showed the best results (Figure 2), giving an RMS surface roughness of 0.1 nm. Al_2O_3 showed the next best surface roughness with an RMS of 0.7 nm. AlN showed the worst surface roughness with 1.0 nm RMS (Figure 3). Varying the deposition conditions such as growth temperature can affect these results. This shows that ALD is capable of depositing materials with ultrasmooth surfaces, which is important for achieving high reflectivity.

Figure 4 shows a graph of the transmission spectra of the basic substrate (Sapphire with AlN template) and depositions of Al_2O_3 and AlN with the substrate. The graph shows both films are reasonably transparent, which is essential for use in DBRs. The similarity of the two films with the substrate show that extinction is not a big issue. However, the graph also shows that the substrate itself is not very transparent, only transmitting approximately 40% of the light. This might suggest that a future possible step could be to remove the substrate through etching or lift off.

In studying growth rates between MBE and ALD, ALD demonstrates considerably slower growth rates at similar plasma powers. It is well known that ALD generally produces inferior crystal structure quality when compared to other growth methods, presenting a challenge if fabricating devices with ALD materials. However, ALD allows for atomically precise thickness control due to the monolayer nature of the process. This makes it possible to finely tune layer thicknesses to achieve complete constructive interference, which gives the highest possible measured peak reflectance.

Future Work:

There are still several factors that need to be explored to determine the viability of ALD as a method for fabrication of DBRs. The main problem that remains is the problem of crystallinity. With a typical epitaxial design consisting of the DBR being inserted between the substrate and the n-type semiconductor region, the low quality or amorphous crystal structures that are often produced by ALD can lead to defects later in the fabrication of the device. One way of getting around this problem would be to use different designs that move the mirror stack to a position in the device where it would have no effect on the structure of the rest of the device. Possible designs may include a dual-DBR stack, a flip-chip design, and several other possibilities.

Other future work will involve characterization of film strain as a possible concern. Also, the dielectric properties of ALD DBRs are an important factor to explore. Furthermore, using different profiles at layer interfaces in place of flat surfaces should be explored.

Finally, given the many possibilities that ALD offers, many other materials should be explored as options for fabricating DBRs.

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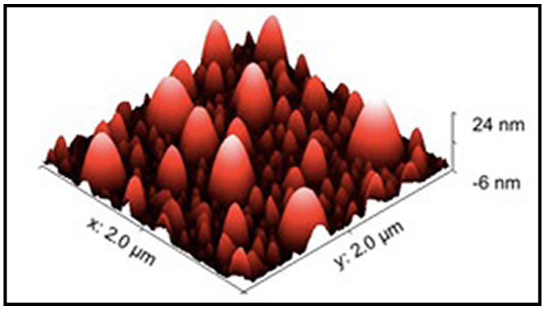

Figure 2: 3D AFM image of 35 nm AlN deposited on an AlN-on-sapphire template substrate. Shows undesirable rough surface.

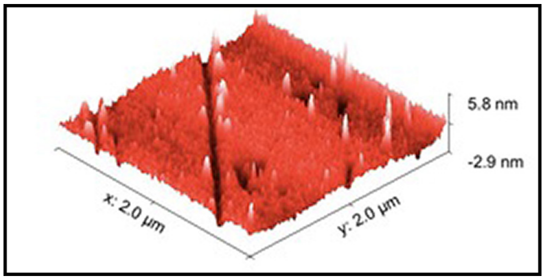

Figure 3: 3D AFM image of 35nm Ta_2O_5 deposited on an AlN-on-sapphire template substrate. Shows desirable smooth surface.

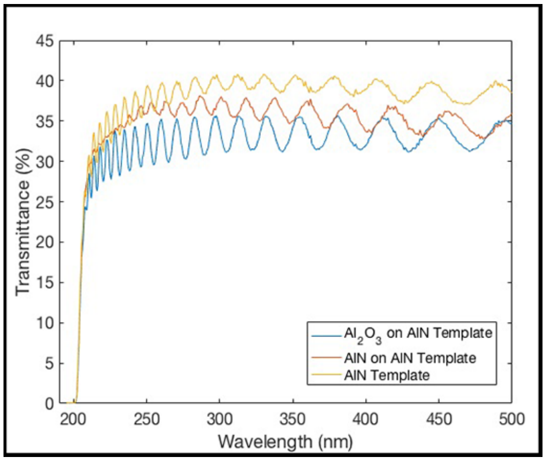

Figure 4: Graph showing the transmission spectra of our substrate, an Al_2O_3 ALD deposition, and an AlN ALD deposition.

References:

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