Wide Bandgap Semiconductor Deep UV Devices

CNF Project Number: 2387-15

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Primary Source of Research Funding: Designing Materials to Revolutionize and Engineer our Future, E70-8276

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Primary CNF Tools Used: Veeco Icon atomic force microscope, ABM contact aligner, photolithography tools (spinners, hot plates, solvent hoods), SC4500 e-beam evaporators, AG610 RTA, PT770 ICP etcher, YES Asher, Oxford 81 RIE, profilometers, Filmetrics

Abstract:

Our main research goal is to improve and fabricate deep UV and visible photonic devices (e.g., LEDs and lasers). We grow the semiconductor thin films by molecular beam epitaxy. We use III-Nitride materials to make such devices. For deep UV devices, wide bandgap materials such as AlN, GaN and AlGaN are the typical materials. *P*-type transport is a major challenge in UV-LEDs. As such, we are working on polarization induced and short period superlattice doping to enhance the active hole concentration in these devices. For visible LEDs, we use tunnel junctions to improve the current spreading and contact resistance.

Summary of Research:

We have grown high aluminum (Al)-content *p*-type transport layers by plasma-assisted molecular beam epitaxy (PA-MBE). These transport layers are grown on MOCVD-grown AlN on sapphire template. Using polarization induced doping, we grew magnesium (Mg)-doped graded AlGaN layers (grading from 100% Al-content to 65%). We also grew Mg-doped AlGaN/AlN short period superlattice structures to compare their performance. AFM images taken in CNF and XRD characterizations are shown in Figure 1.

We used standard lithography tools in CNF to fabricate transmission line measurement (TLM) structures on the *p*-type transport layers. Due to large resistivity in these *p*-type transport layers, we were not able to perform Hall measurements. Therefore, we performed temperature dependent TLM to extract the resistivity of our films and activation energy of the Mg dopant. As shown in Figure 2, the graded *p*-AlGaN structure has improved resistivity over the standard constant *p*-AlGaN structures. These results have been presented in the 2017 international workshop in UV materials and devices in Japan.

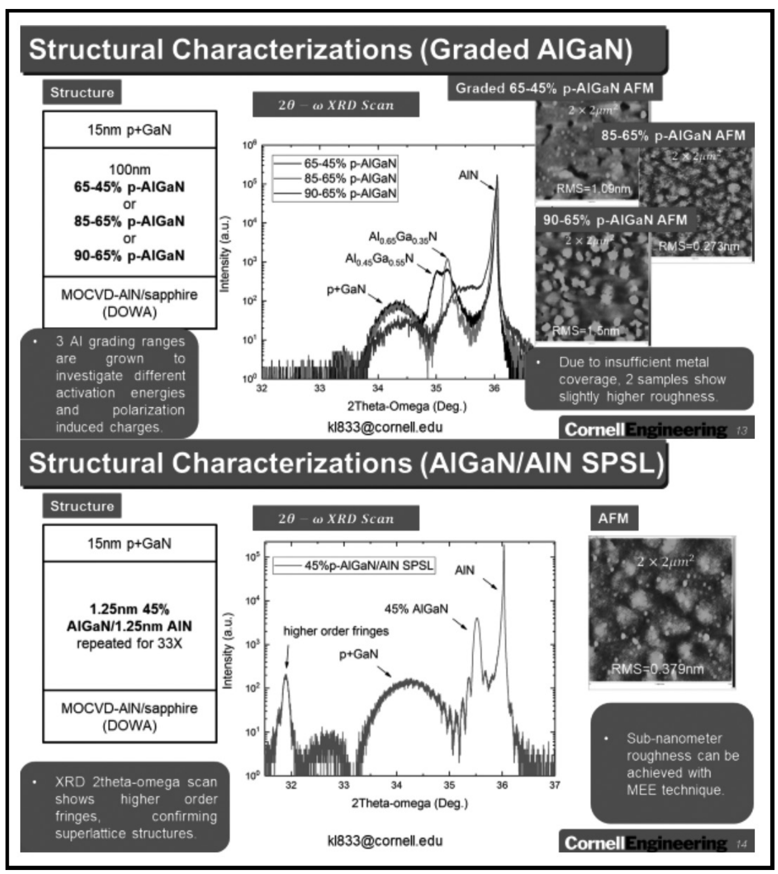


Figure 1: AFMs of grown p-*type transport layers on AlN/sapphire substrate.*

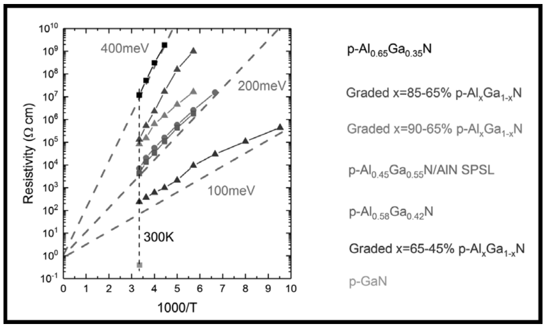
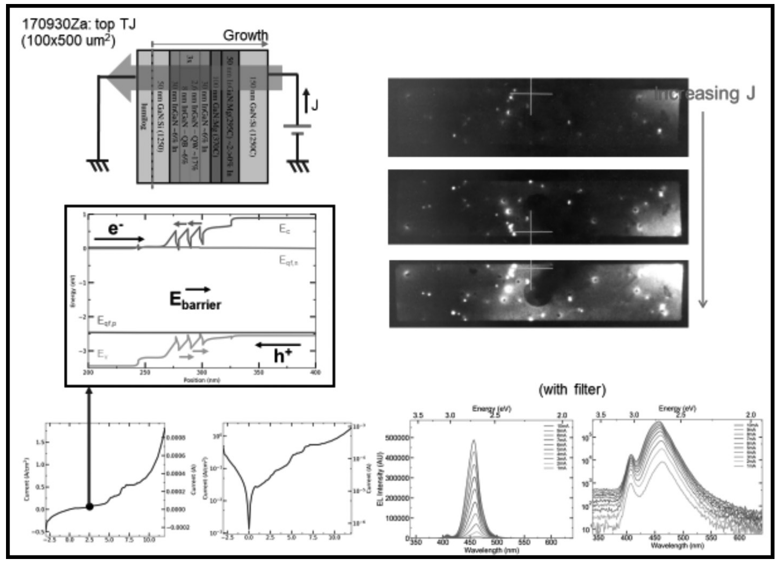


Figure 2, above: Temperature dependent TLM showed two orders less resistivity for graded AlGaN structure over constant AlGaN.

Figure 3, right: Summary of top tunnel junction (TJ) structure's J-V curves and electroluminescence spectrum.



Another approach to resolve the resistive *p*-type layer issue in nitrides is to use tunnel junction. Using tunnel junction, instead of using top *p*-type layer, we grew another *n*-type layer on top of *p*-layer to form a tunnel junction. This is so called top tunnel junction design. Using this strategy, it has two advantages. First, due to low resistivity in *n*-type layer, the current spreading is generally three orders better. Second, making contact to the *n*-layers is also much easier, meaning lower contact resistance.

We grew these structures on single crystal bulk gallium nitride (GaN) substrates. And we used the standard lithography tools to do MESA isolation and put down the contacts. We've successfully demonstrated both top tunnel junction blue LEDs operating at room temperature as shown in Figure 3. The next step will be measuring these devices' external quantum efficiency and output power to benchmark them with respect to other methods.