ULTRAVIOLET LIGHT EMITTING DIODES FOR WATER DISINFECTION APPLICATIONS

This fact sheet summarizes the results of work performed by Crystal IS, Inc. during completion of a NYSERDA project titled "Electrically-efficient, mercury-free, highly-reliable UV light source development for wastewater and drinking water treatment". The research focused on the design, fabrication, packaging, characterization, and commercialization of light emitting diodes (LEDs) for water disinfection.

Ultraviolet light in the 254-280 nm wavelength range is a proven disinfection agent for water. The ideal germicidal wavelength is about 265 nm. The market for ultraviolet disinfection systems is currently dominated by mercury lamps; low pressure mercury lamps produce a monochromatic output of ultraviolet light at 254 nm, whereas medium pressure lamps produce a polychromatic (or broad spectrum) output of ultraviolet and visible light at multiple wavelengths, including the germicidal range. Light emitting diodes (LEDs) are semiconductor devices that emit light of a single wavelength; they can be designed to produce ultraviolet light at the optimal germicidal wavelength. This, and a number of other advantages of ultraviolet LEDs, is presented in Table 1.

Versatility	Operational	Economic & Environmental
○ Compact light source ○ Many different packages ○ Can be packaged in large arrays ○ Mechanically robust	○ Cool running ○ Switchable – no warm-up period ○ Directional Light ○ Single Wavelength	○ Energy efficient ○ Long life ○ Mercury free

Table 1: Advantages of ultraviolet LEDs over mercury lamps for water disinfection applications

LEDs are typically fabricated by depositing very thin, highly crystalline layers of various compositions on a crystalline wafer substrate; these layers are referred to as epi-layers. The wavelength emitted by an LED is defined by the material properties of the epi-layers. The deposited atoms follow the crystalline template provided by the substrate, a process called epitaxial deposition. For most material systems there is a native substrate; for example, for diodes based on aluminum, indium and/or gallium arsenide alloys, the native substrate is gallium arsenide (GaAs), whereas a silicon substrate is used for diodes based on silicon. Crystal IS, Inc. has developed the ability to grow, slice, and polish wafers of single crystal bulk aluminum nitride (AlN), a native substrate for the nitride system, which is used in the fabrication of UV LEDs with short emission wavelength. Figure 1 depicts the fabrication process for ultraviolet LEDs (It is possible to obtain roughly 4,000 individual LEDs from a 2" diameter wafer substrate.).

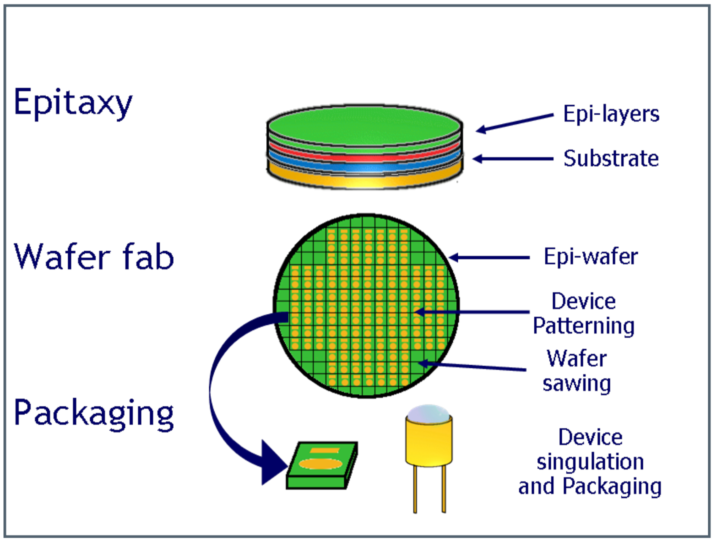

Figure 1: Manufacturing a LED. Epitaxial deposition on the substrate; wafer fabrication (masking, etching, metallization, and device separation); device packaging (mounting, bonding of wires, and electrical connection of device to pins on package)

Aluminum nitride (AlN) and gallium nitride (GaN) alloys are typically used to fabricate ultraviolet LEDs emitting light with wavelength in the germicidal range. Due to the mismatch between the substrate's crystalline template and the natural lattice parameter of the epi-layers, stress accumulates within the epi-layers. This growth regime is called "pseudomorphic growth". At a certain critical thickness, the accumulated stress is released through generation of crystalline defects (dislocations). The growth regime that proceeds after the critical thickness is exceeded is called "relaxed".

nyserda Energy. Innovation. Solutions.

ULTRAVIOLET LIGHT EMITTING DIODES FOR WATER DISINFECTION APPLICATIONS

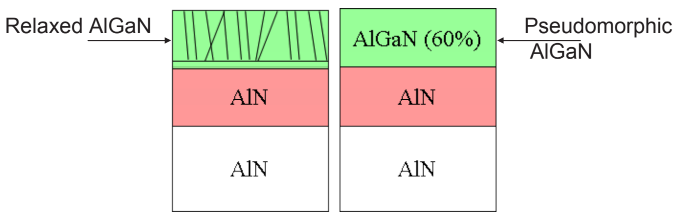

Figure 2: Relaxed (left) and pseudomorphic (right) growth regimes for AlGaN on AlN. In the relaxed growth regime, the layer grows defect free up to a critical thickness after which strain is released through the formation of dislocations. In the pseudomorphic growth regime, although strained, the layer grows without generation of defects.

An unexpected result of the project was observing the growth of thick pseudomorphic nitride layers on the native AlN substrate, layers much thicker than were theoretically thought possible prior to the project. This ability to grow thick pseudomorphic layers correlates with the ability to produce devices with lower defect density, and ultimately, of greater device efficiency. This discovery was capitalized on in a patent application, "Thick pseudomorphic nitride epitaxial layers"; US Patent Application 60/897,572; by Leo J. Schowalter, Joseph A. Smart, Wayne Liu and James Grandusky. These thick pseudomorphic layers, and devices based on them, are not possible when using foreign substrates. Figure 3 shows the emission spectrum and the electro-optical characteristics of a pseudomorphic ultraviolet LED measured on-wafer. At the conclusion of the project, CIS had succeeded in developing ultraviolet LEDs with an emission spectrum peaking at 265 nm and ultraviolet output power of 0.4 mW at 100 mA of injection current.

In order to displace the incumbent mercury-based technology, ultraviolet LEDs require further development to improve device efficiency (i.e., to further reduce losses in the light generating regions and enhance light extraction to the external environment). As device efficiency improves, LEDs will begin to replace the existing ultraviolet light source market as a cost-effective, environmentally-friendly alternative. Initial applications for ultraviolet LEDs will include portable water disinfection for the developing world, disaster situations, the military, and adventure sports; and disinfection for ice makers and water dispensers in high-end refrigerators.

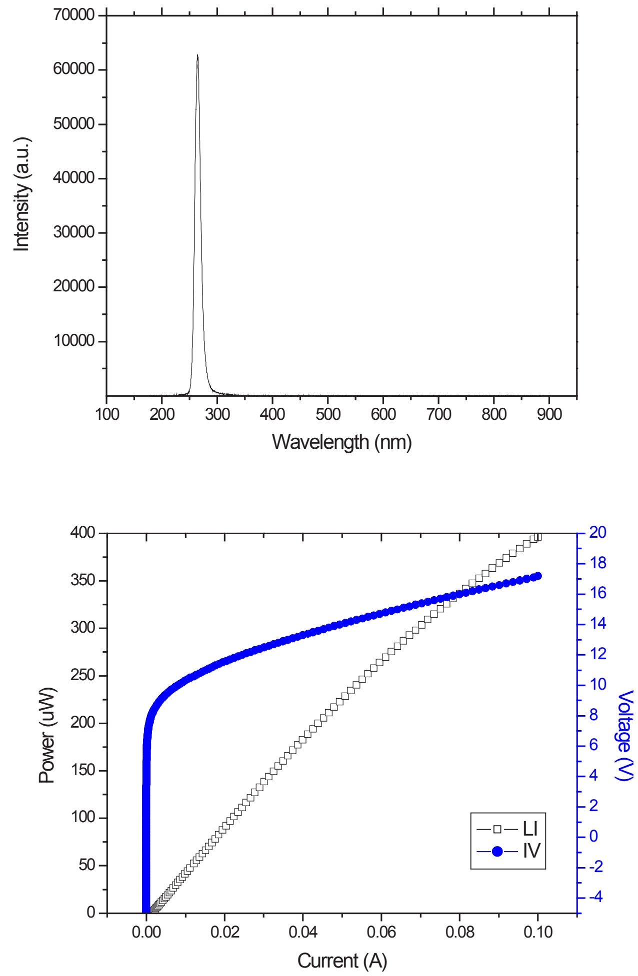

Figure 3: Emission spectrum (left) and electrooptical characteristics (right) of a pseudomorphic ultraviolet LED. The emission spectrum peaks at 265 nm, while the ultraviolet output power of the LED reaches 0.4 mW at 100 mA of injection current.

A number of these applications will be solar-or-battery-powered systems. With further improvement in device efficiency, ultraviolet LEDs will gain access to the pour through and faucet mount water disinfection markets, the portable air purification market, and ultimately, the municipal water and wastewater treatment markets. Crystal IS, Inc. continues to work toward the goal of improving device efficiency, as well as establishing manufacturing partners, and developing strong supply chains.

Crystal IS, Inc. thanks Professor James Malley, from the University of New Hampshire, Karl Scheible, from HydroQual, Inc., and Professor E. Fred Schubert, from Rensselaer Polytechnic Institute for their help and collaboration on the completion of this project. Crystal IS, Inc. is deeply grateful to NYSERDA for its continued support on this endeavor.

nyserda Energy. Innovation. Solutions.