Deep UV LED efficiency reaches 3%

External quantum efficiency of 5% for 255–280nm single-chip LEDs within reach.

Researchers based in Nagoya, Japan have reported deep ultraviolet (255–280nm) LEDs with external quantum efficiencies (EQEs) of up to 3% [Cyril Pernot et al, Appl. Phys. Express, vol3, p061004, 2010]. The output power was up to 1mW at 10mA. The researchers predict that an EQE of 5% for UV-C (280–100nm) single-chip LEDs is within reach.

The researchers — from UV Craftory Co Ltd, Meijo University, EL-SEED Corp and Nagoya University — see applications in replacing mercury lamps with alternatives that are more compact, efficient, safer (no mercury) and versatile (with a wavelength range between 360nm and 200nm, rather than single wavelengths, determined by mercury emission line spectrum, at 184nm, 254nm, 365nm...).

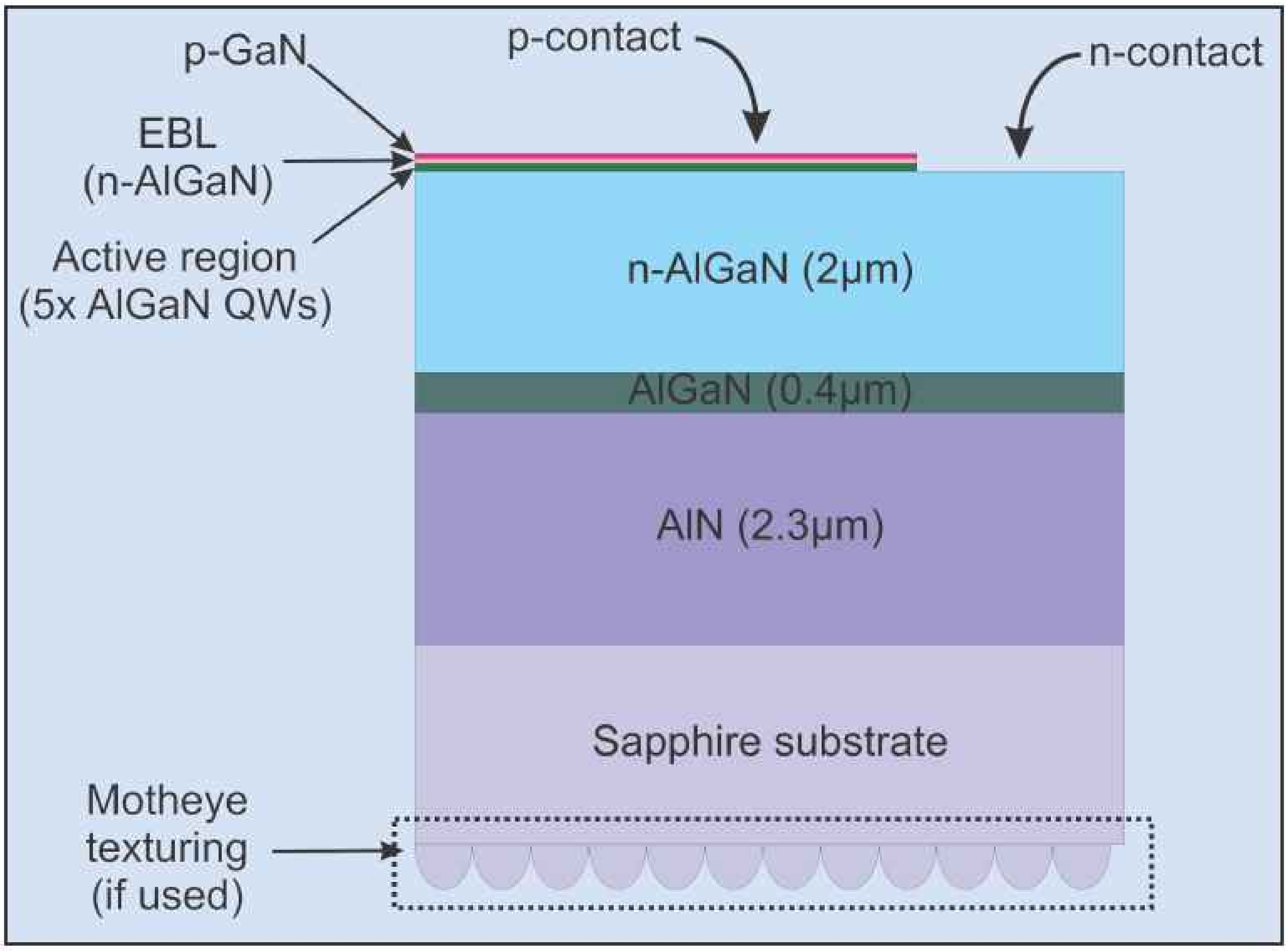

Figure 1. Deep UV LED epi with moth-eye structure on sapphire substrate.

Systems using DUV LEDs are being developed for sterilization, water purification and surface disinfection. Other applications include curing of materials such as adhesives, spectrometry, medical therapies and currency validation.

The leading material system for LEDs in this wavelength range is aluminum gallium nitride (AlGaN), with energy bandgaps up to 6.2eV (wavelength down to ~200nm) for pure AlN. However, as the target wavelength gets shorter, it becomes more difficult to produce high efficiency devices. In particular, for the wavelength range below 280nm, external quantum efficiencies have been less than 2% up to now.

One major restriction on UV LED development is the p-type contact. The Al-content (if any) of the p-AlGaN layer has to be kept small for reasonable activation (already less than ideal in pure GaN) of the magnesium doping used. However, the AlGaN energy bandgap at these low Al-contents is narrower than the target wavelength and hence the p-contact is highly absorbing of the UV emitted by the active region. Developers of DUV devices are therefore forced to extract light mainly in the opposite direction, through the substrate. This is achieved through flip-chip packaging arrangements.

Although the n-type doping achieved by silicon doping can be carried out acceptably with higher Al-content AlGaN, the material is more resistive, making heat generation a greater problem compared with longer wavelength devices. Thermal management is therefore also important in achieving acceptable device performance.

The devices were grown using MOCVD with trimethyl-metal and ammonia sources (Figure 1). The Al-content of the AlGaN quantum wells controlled the emission wavelength (40%, ~280nm; 57%, 255nm). A p-AlGaN electron blocking layer (EBL) was used to prevent electron overshoot into the p-type contact region.

The LEDs consisted of 800μm x 800μm mesas with nickel alloy and gold bonding pads for the p-contact and aluminum alloy and gold bonding pads for the n-contact. The chips were flipped onto thermally conductive AlN submounts. The mounted devices were installed in TO5 transistor outline packages.

Pulsed (10Hz, 20% duty cycle) and continuous wave (CW) operation were used to evaluate the devices. A 257nm device had a turn-on voltage of 5.5V and a forward voltage of 6.3V at 20mA. At this injection current, the full-width half-maximum (FWHM) value of the spectral peak was 10nm. The output power at 20mA was more than 2.8mW and the maximum EQE

3% for all the devices studied (Figure 2). The peak wall-plug efficiency is estimated at 2.2%. Some 10mW output was achieved at 66mA and 1mW at 8mA.

Self-heating effects tend to degrade the LED performance in CW operation at high currents. For the 257nm device, the output power was more than 1mW at 10mA (CW) without a heat-sink.

"The improved n-AlGaN quality allowed us to achieve these results, which are, to the best of our knowledge, the best reported to date for single-chip UV-C devices," comment the researchers. The improved n-AlGaN was achieved through depositing it on the thick AlN layer that was grown at high temperature on the initial sapphire substrate.

The researchers also looked at the effect of the moth-eye structuring of the sapphire substrate on light extraction by producing 270nm devices both with and without the patterning (Figure 3) and a 1.5-fold improvement was seen. The moth-eye structure is created on the sapphire wafer back-side (i.e. away from the active nitride semiconductor layers). Such structures have been used by the same research group with blue LEDs on silicon carbide substrates to boost light extraction.

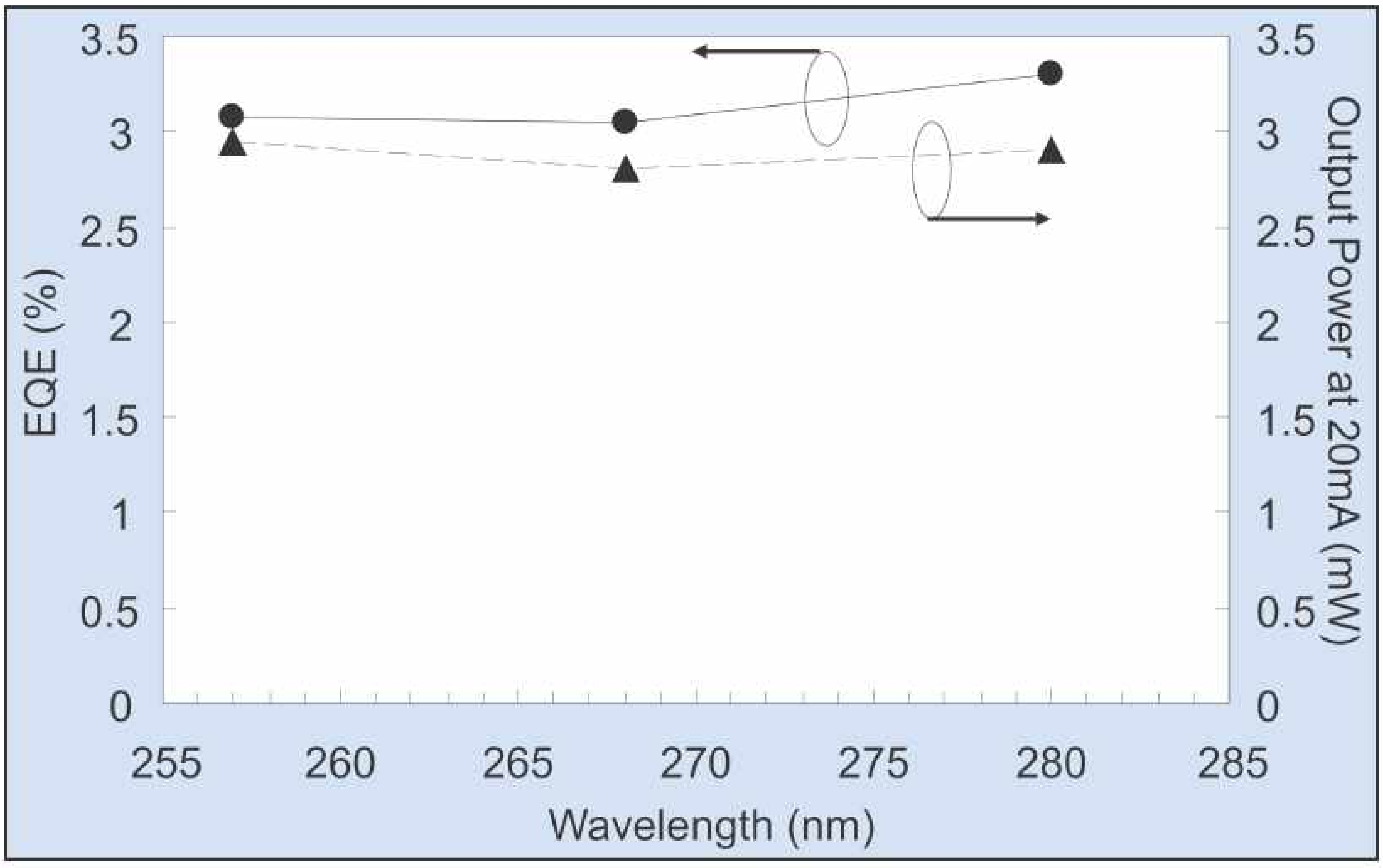

Figure 2. Maximum EQE and output power at 20mA for 257, 268 and 280nm LEDs.

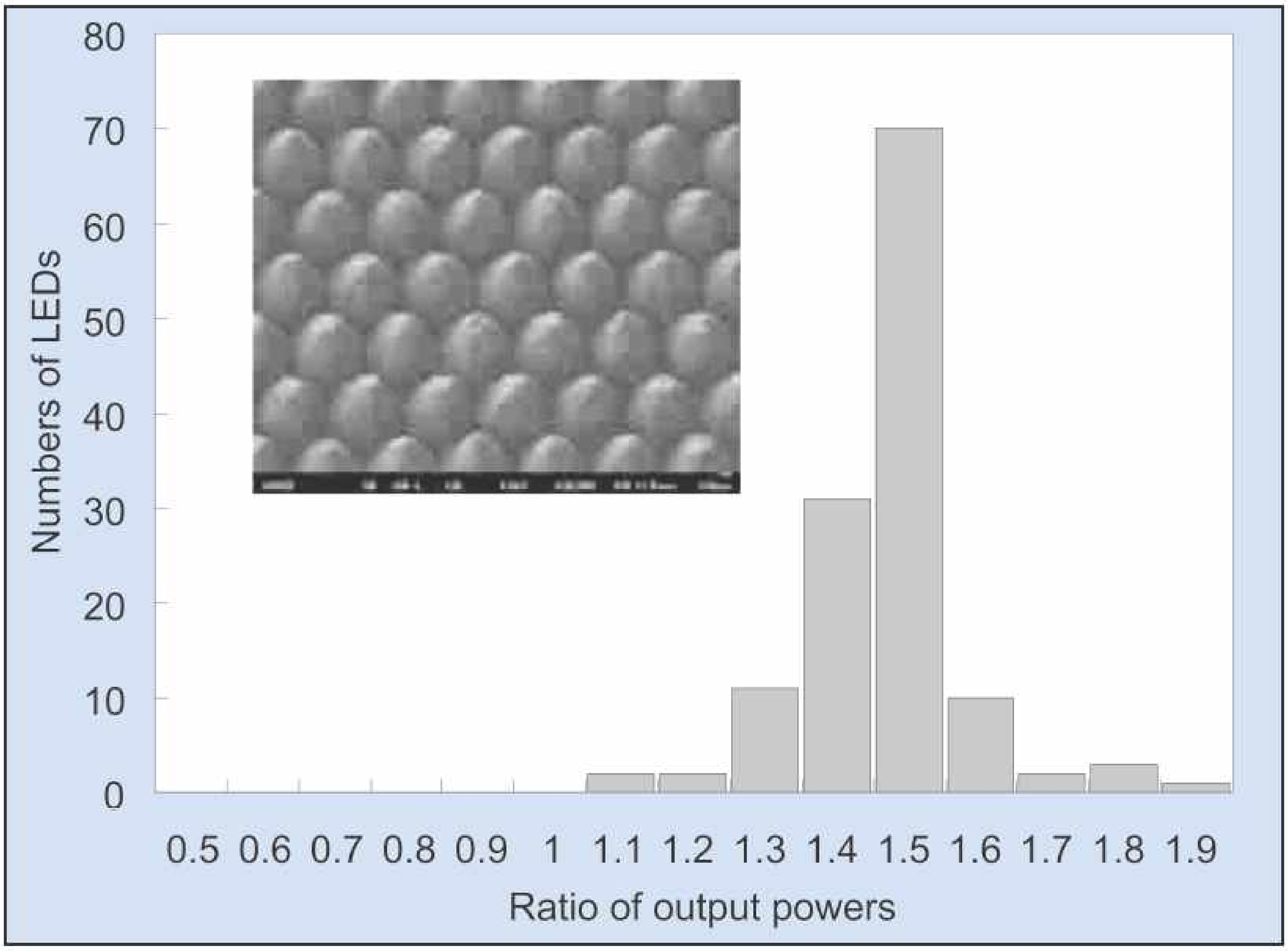

Figure 3. Histogram of light output power ratios for 270nm LEDs with and without moth-eye structure. Inset: scanning electron micrograph (SEM) of moth-eye structure fabricated on back-side of sapphire substrate.

The improvement for new devices is lower than for blue LEDs because the DUV light cannot undergo multiple reflections in the p-contact region, the researchers believe. The team wants to optimize the moth-eye structure for DUV emission in future work.

The researchers also performed reliability studies — at 10mA (CW), the output power was maintained at more than 75% of its initial value for 300 hours. This value is expected to be lengthened by improving the heat management of the devices through package optimization.

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