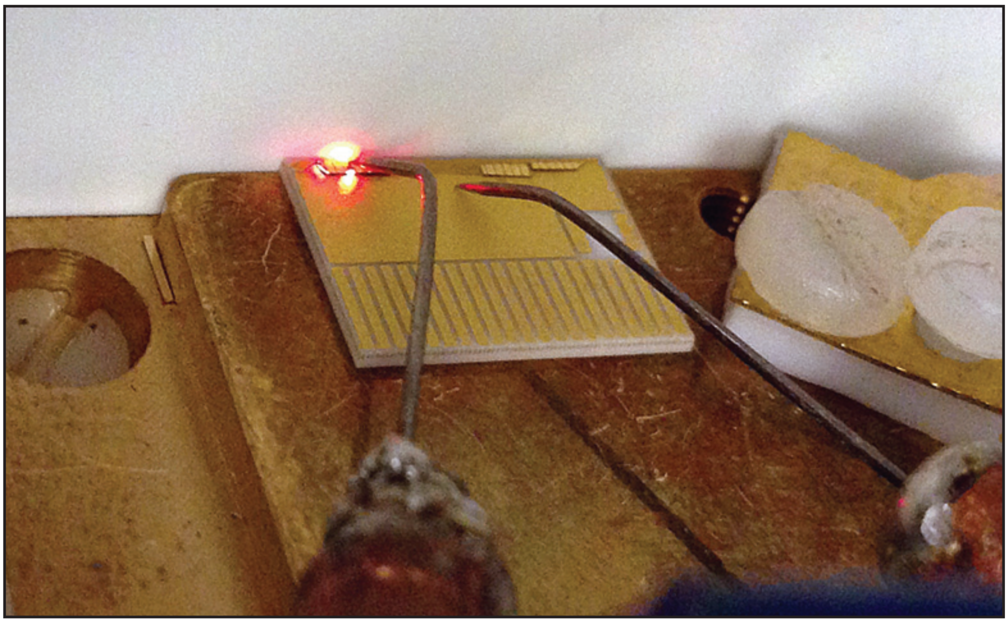
FURTHER READING

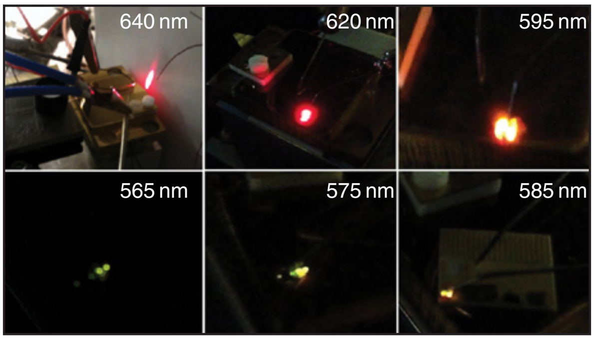
Page 1102
'First demonstration of InGaP/InAlGaP based orange laser emitting at 608 nm', M.A. Majid, A.A. Al-Jabr, H.M. Oubei, M.S. Alias, D.H. Anjum, T.K. Ng and B.S. Ooi

First demonstration of InGaP/InAlGaP-based 608 nm orange laser using a cost effective approach, with potential applications in lighting and VLC

rainbow bridges



The first demonstration of an InGaP/InAlGaP- based orange laser emitting at 608 nm has been reported by researchers in Saudi Arabia. Using a cost effective approach, the work is aimed at filling a wavelength gap in the visible spectrum for commercial semiconductor lasers, enabling a wide range of uses including lighting and VLC.



TOP: The orange laser produced using the thick dielectric cap and annealing approach at KAUST
BOTTOM: Demonstration of the novel strain-induced intermixing process starting from red laser material at 640 nm through materials engineered to emit at smaller wavelengths, all the way down to greenish-yellow at 565 nm

Gaps in coverage

In order to provide light sources across the wavelengths of the visible spectrum, visible semiconductor lasers (VSLs) use a range of materials. Nitride-based material systems (InGaN/GaN) are available for violet to green wavelengths (~405–530 nm) and phosphide-based (InGaP/InAlGaP) cover the red spectrum (635–690 nm). The green-yellow-orange range (~530–635 nm) is not covered by commercially available VSLs.

Covering the full visible range is important for applications like solid-state lighting and visible light communication (VLC) systems, where lighting sources are used to communicate data as a secondary function. The full coverage of the visible spectrum with commercially viable VSLs would allow semiconductor lighting systems with higher colour rendering index (CRI), a measure of how well light sources reproduce the colour of objects in natural lighting, and increase the capabilities of VLC systems including Li-Fi. VLC bandwidth would be increased by allowing more frequencies to be used and the data rates possible would be raised as lasers can be modulated much more quickly than LEDs, allowing GHz modulation bandwidth.

Ideally, the existing nitride or phosphide-based material systems should be used to cover this missing range, as this would reduce the complexity and costs of producing such VSLs, but there are issues with extending the wavelength coverage of both. For the phosphide-based systems, small band offset between the quantum-well (QW) and barriers leads to small carrier confinement and large carrier leakage, prohibiting the growth of high quality quantum well structures for green-yellow-orange emission. For the nitride-based QW structures, large strain and indium segregation prevent the growth of high quality light emitting devices in this colour range.

Shifting strain

In this issue of *Electronics Letters* the team of researchers from the Photonics Laboratory at King Abdullah University of Science & Technology (KAUST) present a phosphide-based laser structure that can operate down to 608 nm in the orange wavelengths at room temperature. The approach they use has actually allowed them to tune the bandgap of an InGaP/InAlGaP structure from 640 nm in the red spectrum to 565 nm just inside the start of the green spectrum.

Their approach is to apply a thick dielectric layer (silicon oxide) to induce significant strain to the QW region without damaging the contacts or p-cladding, then annealing to promote quantum well intermixing (QWI). This works because the high strain causes atoms in the thin InGaAlP quantum barrier and the InGaP quantum well to interdiffuse. The result is grown-in strain relaxation and an atomic composition change, shifting the bandgap of the materials. They found that the dielectric layer needs to be at least as thick as the upper cladding layer of the QW to achieve the shift in emission wavelength and avoid degrading the surface morphology and the electrical and optical characteristics. It was also necessary to use a modified annealing process.

"Conventional annealing methods require the introduction of impurities into the semiconductor and anneal the structure at very high temperatures to promote QWI. This will form extended defects and degrade the quality of the laser structure. Our method of using the thick dielectric cap layer to encourage QWI is essentially an impurity free process, allowing annealing at a lower temperature in multiple cycles to prevent the formation of defect clusters," explained KAUST team member Prof. Boon Ooi.

Lighting and Li-Fi

The photonics laboratory at KAUST have also applied their approach to LEDs and have demonstrated green, yellow, orange, high-brightness red and red LEDs. "Our team's wider goal is to develop high quality lighting solid-state technologies using RYGB LED and laser solutions. The demonstration of high performance yellow LED and lasers will pave the way for this," said Ooi.

"Over the next decade I hope to see the development of high performance visible light emitting devices that will bridge the true green and yellow gaps, and enable the coverage of wavelength span between 550 nm (true green) and 640 nm (red) for broad applications in solid-state lighting and visible light communications. This will enable full spectrum, ultra-high CRI lighting, as well as multiple wavelengths, terahertz visible light communication systems."

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