Room temperature yellow InGaAlP quantum dot laser

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Yellow lasers are important for applications in flow cytometry, confocal and light sheet fluorescence microscopy, photodynamic therapy, dermatology, ophthalmology, process control, and many other fields. Laser diodes represent the most compact, cost- and energy-efficient solution for these applications, particularly when multiple wavelengths must be applied in the same device. Unfortunately, commercial laser diodes are available only at wavelengths either shorter than 520–525 nm (covered by gallium nitride-based devices) or longer than 630–635 nm (covered by InGaAlP lasers on GaAs substrates). An important spectral range of true green, yellow, orange and bright red (620 nm) is covered mostly by frequency conversion schemes using non-linear optical crystals and diode-pumped solid-state lasers. On top of relative complexity, such approaches provide only a limited number of suitable wavelengths and prevent continuous wavelength tuning that would be useful in many cases. For mass-market display applications, the bright red spectral range (~620 nm) requires a large number of lasing modes and spectral broadening to avoid speckle in the resulting color images.

There were multiple attempts to bridge the yellow-green gap coming from the red side. The ultimate room-temperature wavelength, previously realized in InGaAlP lasers, is in the red-orange spectral range: 615 nm [1].

Some time ago, we proposed [2] that multiple ultrathin GaP-rich tensile-strained insertions in combination with growth on surfaces close to the (111) crystal orientation may allow the realization of efficient barriers for nonequilibrium electrons, blocking their escape from the active region. Epitaxial growth on surfaces close to (100) orientation, on the other hand, did not provide significant advantages. With this approach green and yellow lasers were realized at 80 K [3].

Recently, we further improved the design to reach lasing in the 590–610 nm wavelength range at room temperature by employing (211) and (322) GaAs substrates and GaP barriers. The active gain region is based on stacked InGaP insertions that form vertically-coupled self-organized quantum dots when grown on high-index surfaces. On top of enabling a novel class of laser diodes, the observation is important for the improvement of properties of InGaAlP laser diodes in the orange (615 nm) and bright red (620 nm) spectral ranges, making the devices suitable for high power applications.

We will also discuss further options for substantial wavelength shift towards the green.

1. H. Hamada, "Characterization of gallium indium phosphide and progress of aluminum gallium indium phosphide system quantum-well laser diode", *Materials* **10**, 875 (2017).
2. N. N. Ledentsov, V. A. Shchukin, and J. A. Lott, "Ultrafast nanophotonic devices for optical interconnects", chapter in S. Luryi, J. M. Xu, and A. Zaslavsky, eds., *Future Trends in Microelectronics: Into the Cross Currents*, New York: Wiley, 2013, pp. 142–159.
3. N. N. Ledentsov *et al.*, "(In,Ga,Al)P–GaP laser diodes grown on high-index GaAs surfaces emitting in the green, yellow and bright red spectral range", *Semicond. Sci. Technol.* **32**, 025016 (2017).