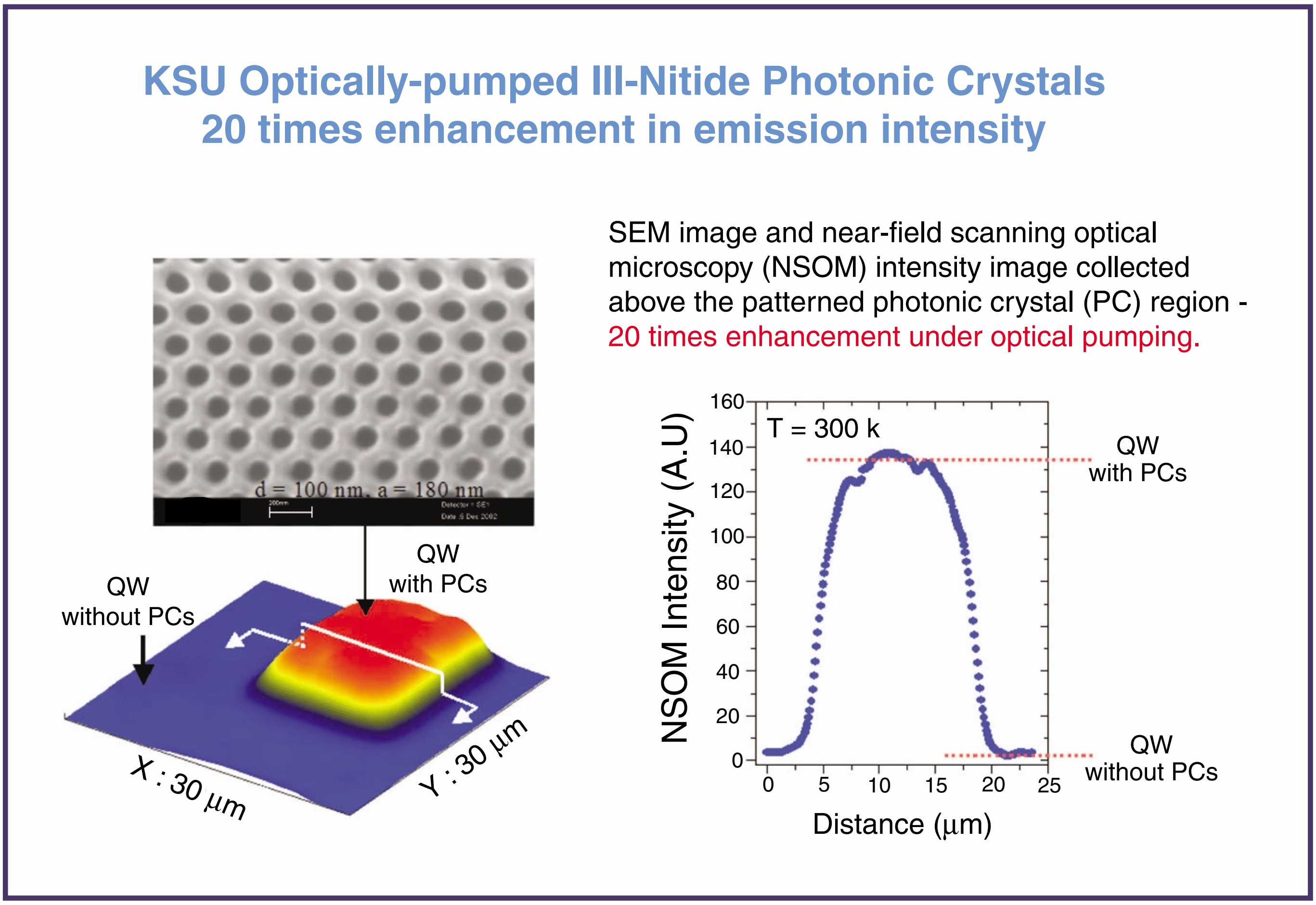
The development of compound semiconductor photonic crystals (PCs) based on infrared devices (wavelengths longer than 700nm) has been quite rapid during the last few years, mostly focused on Indium Phosphide materials for optical communication uses in the 1.3 and 1.55nm transmission windows. The property being exploited is the ability of lattices of varying refractive index to form photonic bandgaps in which the propagation of specific light wavelengths is prohibited or modified. This property can be used to control or enhance the spontaneous emission and or light extraction efficiencies from both active and passive devices (including LEDs).

Dr Alan Mills
Contributing Editor

First time III-Nitride photonic crystals

However, since light extraction varies inversely with the square of the refractive index, only about 5% of the light can be extracted per surface for phosphide materials based devices. Even though III-nitride materials tend to have lower refractive indices (than phosphides) and therefore would have a better light extraction potential, little work has been done on the green, blue and UV emitters to exploit these benefits. The presumed reason for this lack of progress is the difficulty in producing those sub-micron periodicities needed for the PCs.

Figure 1



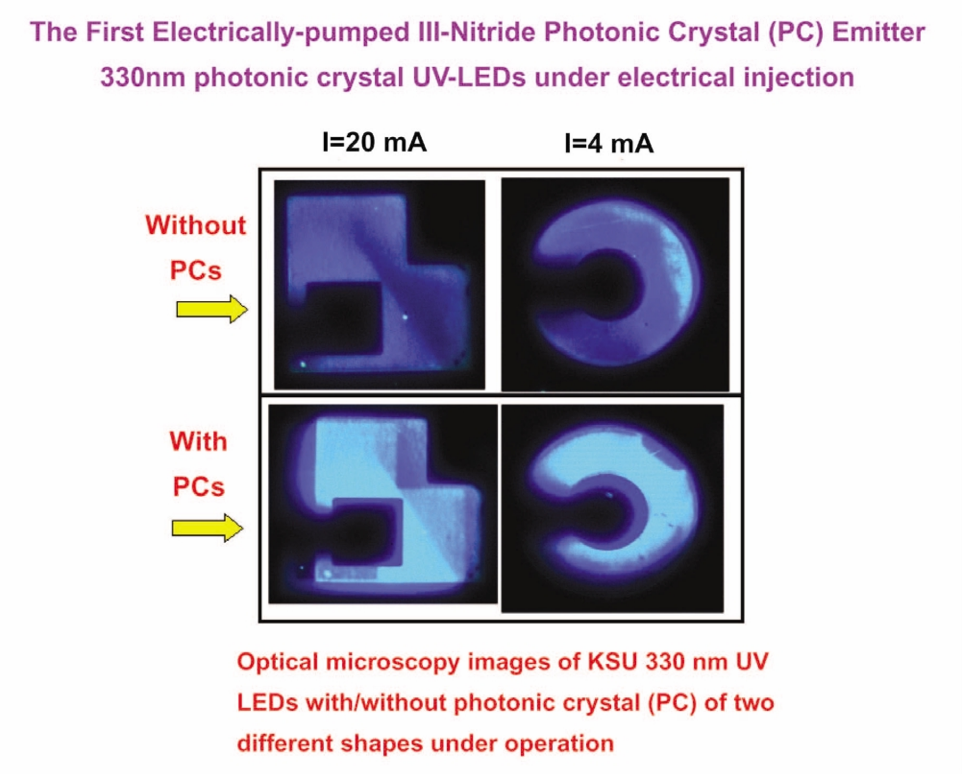


Figure 2

However, due to research at Kansas State University (Manhattan, Kansas), supported by several US government agencies, another leap forward has taken place in nitride emitter technology. From this research Tom Oder and co-workers have reported the nanofabrication of triangular lattice III-nitride photonic crystals on LED devices in a recent series of papers (including one at the December MRS Meeting).

Here, periodicities in the 100 to 180nm range were reported based on new nitride PCs formed by a combination of e-beam lithographic and inductively-coupled-plasma dry etching techniques (see Figure 1). In this illustration, dimension a) represents the lattice constant at 180nm and d) the size of the PC hole at 100nm.

Under optical pumping and room temperature conditions, InGaN/GaN quantum well LEDs (with photonic crystals) produced an unprecedented 20-fold increase in the intensity of the emitted light at 475nm (see Figure 2).

Electrically driven photonic crystals have also been fabricated on blue LEDs (460nm) and UV LEDs (330nm), which with current injection, produced up to three times the optical power output over the conventional LEDs as measured by a CCD camera (Figure 2). Near-field scanning optical microscopy (NSOM) measurements of the PCs showed a 60° periodic variation between the propagation direction of the emitted light and the PC lattice, a direct result of the desired photonic band structure.

These results are very important for the future potential of blue, green and UV solid state light emitters, where their shorter emitting wavelengths are very desirable. To date, high optical output powers and high external efficiencies have been difficult to achieve.

If these PCs can be reproduced on a commercial basis in the future, the combination of the lower refractive indices of nitride device materials and the use of photonic crystal wave-guides could greatly enhance LED and LD light extraction and the output power efficiencies of emitters in the 200 to 500nm wavelength range.

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