Dilute Nitride Materials for Mid-infrared Optoelectronic Devices

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BIOGRAPHY

Tony Krier is professor of physics at Lancaster University. He obtained his PhD in 1983 and joined Lancaster in 1989, where he founded the mid-infrared optoelectronics research group. He was promoted to Reader in 1999 and then to Professor in 2003. He is currently head of the condensed matter research division and has published more than 170 papers and successfully graduated 20 PhD students. He has worked extensively on the fabrication and characterization of lasers, LEDs and photodetectors for the 2-5 \( \mu \text{m} \) spectral range. In 1996 he founded the international mid-infrared materials & devices conference (MIOMD) and in 2006 he edited a specialist book on mid-infrared optoelectronics. His recent work concerns antimonide nanostructures and dilute nitride alloys for use in mid-infrared lasers and photodetectors.

TECHNICAL ABSTRACT

InAsN dilute nitride alloys have great potential for the development of optoelectronic devices operating in the technologically important mid-infrared spectral range [1-3]. In this work we report on the epitaxy of bulk and quantum well InAsNSb dilute nitride structures which exhibit light emission within the 2-5 \( \mu \text{m} \) wavelength region. The growth of InAsNSb is of particular interest because one can envisage novel type I strain balanced quantum wells on InAs substrates for use in diode lasers and LEDs. The samples were grown by molecular beam epitaxy (MBE) using a nitrogen flux of 6\( \times 10^{-6} \) mbar and a plasma power of 160 W. The structural and optical properties of the resulting material were studied using electron microscopy, high resolution X-ray diffraction and photoluminescence spectroscopy.

![Photoluminescence spectra](image1.png)

**Fig. 1** (a) Photoluminescence spectra at \( T = 4 \text{ K} \) for InAsN epilayers grown on GaAs substrates with nitrogen content in the range \( N = 0 - 1 \% \). (b) Dependence of \( E_0 \) and \( \Delta_0 \) on the N content as derived by photoreflectance [5]. The squares correspond to the PL peak energies for InAsN epilayers (\( T = 4 \text{ K} \)).

We obtained material of good crystalline quality with a residual carrier concentration of 2\( \times 10^{17} \text{ cm}^{-3} \). Photoluminescence was observed from InAsN alloys with N contents up to 2.5\% in excellent agreement with the band anti-crossing model and which exhibited localization effects [4]. As the N content is increased, the InAsN samples...
exhibit progressively higher activation energies with respect to thermal quenching. As the nitrogen content increases above 0.5\%, the band gap energy, $E_0$, becomes smaller than the spin orbit split-off energy, $\Delta_0$. Figure 1 compares the PL peak energy of our InAsN epilayers with the values of $E_0$ and $\Delta_0$ measured by photoreflectance [5], which indicates that the nitrogen-induced change of the band gap acts effectively to detune CHSH Auger recombination.

Furthermore, our studies have also shown that the addition of Sb to InAsN increases the incorporated nitrogen concentration and at the same time improves the optical properties [3]. Ten-period InAsNSb/InAs multi-quantum wells were successfully grown and exhibited bright photoluminescence up to 250 K without any thermal annealing. Our observations are consistent with $e$-$hh_1$ and $e$-$lh_1$ transitions within type I quantum wells and are in good agreement with calculations. These MQW were then embedded within the active region of a prototype InAs based LED as shown in figure 2.

Electroluminescence was obtained from dilute nitride InAsSbN/InAs multi-quantum well light emitting diodes which exhibited bright emission in the mid-infrared peaking at 3.56 $\mu$m at room temperature [6]. InAsN offers an attractive opportunity to gain access to the mid-infrared spectral range and has the advantages of a type I QW, with the benefit of $\Delta_{so} > E_c$ and within which Sb can be used to tailor strain. Consequently, this material system shows promise for use in mid-infrared diode lasers and other optoelectronic devices.


**Keywords:** Dilute nitrides, electroluminescence, photoluminescence, mid-infrared, MBE growth, quantum wells