Near room temperature electrical injection lasing for dilute nitride Ga(NAsP)/GaP quantum-well structures grown by metal organic vapour phase epitaxy

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Electrical injection lasing has been verified for GaP-based broad-area Ga(NAsP)/GaP single-quantum-well heterostructures near room temperature for the first time. The lasers have been grown by metal organic vapour phase epitaxy. Owing to the comparable lattice constants of this novel material system to that of Si, this novel dilute nitride III/V laser material might be applied for optoelectronic devices integrated to Si microelectronics in the future.

Introduction: The dominant semiconductor material for electronic and microelectronic circuit applications is Si. Owing to its indirect bandgap, however, efficient light emission from Si has been found to be very difficult. Therefore, direct compound semiconductors and related low-dimensional carrier systems based on GaAs or InP have been applied to realise efficient optoelectronic devices and integrated circuits. One severe drawback in integrating III/V compound opto-electronic circuits to Si microelectronic applications is the large difference in lattice constants of the standard GaAs- and InP-based material systems from that of Si. This leads to the formation of a large number of misfit dislocations [1], which also act as non-radiative recombination centres, preventing the realisation of any long-term stable III/V laser devices on Si substrate up to now.

Recently, we have introduced the novel dilute nitride material system Ga(NAsP), which can be grown pseudomorphically strained on GaP substrate. The high crystalline perfection in this novel material system without any misfit dislocation formation is verified by high-resolution X-ray diffraction (XRD). The findings reported here for the deposition on GaP can be transferred in a straightforward way also to the deposition on Si owing to the similar lattice constants of GaP and Si [2]. Applying optical spectroscopy techniques we have verified the direct bandgap characteristics of Ga(NAsP)/GaP multi-quantum-well heterostructures (MQWH) [3]. Lasing activity in this novel MQWH-system has been found by applying optical pumping techniques for temperatures up to room temperature. In addition, first electrical injection laser structures have been realised, which exhibit lasing characteristics at low temperatures in the range 80–150 K [4, 5].

In this Letter, we report on laser characteristics under electrical injection for broad-area Ga(NAsP)/GaP SQWH laser structures for the first time near room temperature. The lasers have been grown by low-temperature metal organic vapour phase epitaxy (MOVPE).

Experimental setup: The Ga(NAsP)/GaP-based QWH layers have been deposited in a commercial horizontal reactor system (Aix 200-GFR) at reduced pressure of 50 hPa in hydrogen carrier gas on *n*-(100) GaP:S exactly oriented substrates. Low deposition temperatures at 575°C have been used applying the more efficiently decomposing group-V sources tertiarybutyl arsine (TBAs), tertiarybutyl phosphine (TBP) and 1,1-dimethylhydrazine (UDMHy) in combination with the group-III source triethylgallium (TEGa). For the device structures the 400 nm thick nominally undoped GaP separate confinement (SCH) layer contains one 6.4 nm-thick Ga(NAsP) SQWH in the centre of the SCH. For the formation of a waveguide structure this layer stack is embedded in between 1.5 µm thick *n*-($Al_{0.23}Ga_{0.77}P$):Te and *p*-($Al_{0.23}Ga_{0.77}P$):Zn, which have been deposited at 725 and 675°C, respectively, using TEGa and trimethylaluminum (TMAl) in combination with TBP. In addition, 300 nm-thick *n*-GaP:Te and p^+-GaP:Zn layers have been used as buffer and contact layers, respectively. More details, in particular about the MOVPE growth process in our cluster tool, can be found elsewhere [4].

Broad-area laser structures have been processed by depositing 50 µm wide Au/Cr metal stripes on the *p*-contact layer. Au/Ni/AuGe-based back contacts have been applied. Laser facets are formed by standard cleavage techniques owing to the deposition on GaP substrate. For part of the laser bars, the facets have been coated by standard high reflectivity layers.

The individual laser bars have been mounted *p*-side up on CuW submounts and finally mounted on 2 mm C-mounts. The *p*-contact has been connected by direct wire bonding of the 50 µm top stripe metal layer. For the experiments, the lasers were mounted in a developed HF high-power arrangement. The temperature was controlled by a Peltier cooler and an LDC 3744B temperature control unit. Square current pulses of 100 ns duration at repetition frequencies of 0.005, 1.0 and 10 kHz were produced with a pulse generator AVTECH AVOZ-A3-B. With this generator a maximum pulse amplitude of about 100 A can be generated. The amplitude of the current pulse in the laser diode was estimated from the voltage drop across a 1 Ω resistor. The optical output of the laser was sent to a fast Si photodiode (C5331-04) connected to a TDS 754 oscilloscope. Owing to the time interval of about 100 µs or longer between two successive current pulses (corresponding to a repetition rate of 10 kHz), which is very long when compared with the recovery time of the active medium, effective single-pulse excitation is realised.

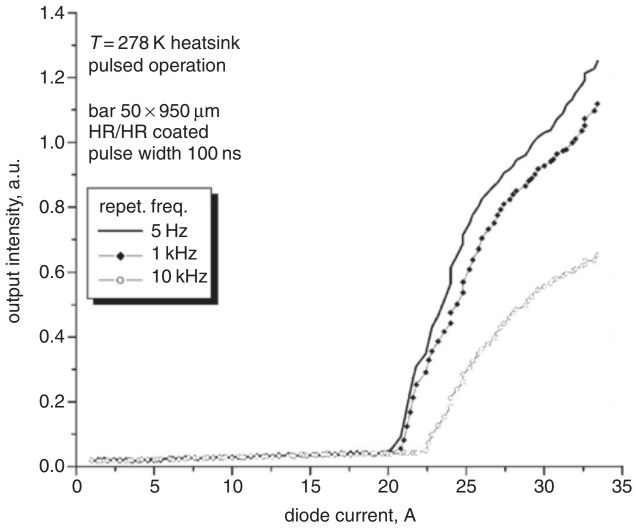

Fig. 1 *Light/current characteristics of broad-area Ga(NAsP)/GaP SQWH LD under pulsed operation at heatsink temperature of 278 K for different repetition frequencies*

Results: The light-output/current (L/I) characteristics under pulsed operation were determined by stepwise increasing the current pulse amplitude and measuring the photodiode signal with the oscilloscope. The L/I characteristics under pulsed operation of one Ga(NAsP)/GaP SQWH broad-area laser diode (BA-LD), having a cavity length of 950 µm, are shown in Fig. 1 for different pulse repetition frequencies at a heatsink temperature of 278 K.

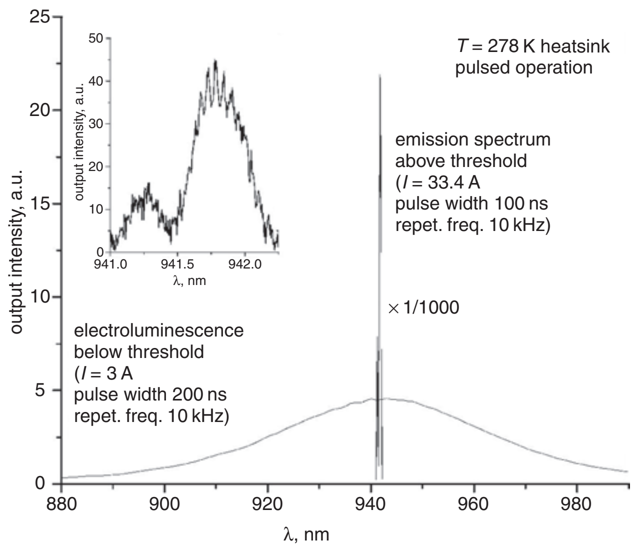

Fig. 2 *Spectral emission characteristics of broad-area Ga(NAsP)/GaP SQWH LD under pulsed operation at heatsink temperature of 278 K for currents below threshold (electroluminescence spectrum lower trace) and above threshold (laser spectrum upper trace)*

Inset: Mode structure of LD above threshold

A clear threshold type behaviour is observed for a current of about 20 A, resulting in a threshold current density of 42 kA/cm^2 for these first non-optimised SQWH device layers using the novel Ga(NAsP)/GaP material system. This high threshold current density as well as the detected heating effects of the device with an increase in repetition frequency are due to significant non-radiative recombination processes still present in the structures studied. Future work will focus on the optimisation of the MOVPE growth and annealing conditions of the novel Ga(NAsP)/GaP material system as well as in improvements of the optical confinement factor and in the electrical confinement by applying an optimised design for the waveguide structures.

The spectral emission characteristics of the Ga(NAsP)/GaP SQWH BA-LD below and above threshold are summarised in Fig. 2 for a heatsink temperature of 278 K under pulsed electrical injection conditions. The electroluminescence spectrum (lower trace in Fig. 2) peaks at an emission wavelength of 943 nm with an emission line width of 66 meV (FWHM). Above threshold the emission spectrum (upper trace in Fig. 2) narrows drastically and a clear mode spectrum is detected (inset of Fig. 2), which proves the successful realisation of an electrical injection laser in this novel material system around room temperature.

Conclusions: The near room temperature lasing behaviour of broad-area GaP-based Ga(NAsP)/GaP SQWH laser structures under pulsed electrical injection conditions has been verified for the first time. The proof of concept, as described here, might lead to the application of the novel Ga(NAsP) material for laser devices integrated to Si-based microelectronics in the future. Improvements in laser characteristics are expected by careful optimisation of the MOVPE growth conditions in the novel Ga(NAsP) material system, of the post-growth annealing process and of the device layer design with increased optical and improved electrical confinement.

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