Lasing properties of monolithically integrated Ga(NAsP)/(BGa)P QW lasers on a Silicon substrate grown by MOVPE

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Abstract-Lasing operation up to 120K is reported for direct band-gap GaNAsP grown monolithically on a silicon substrate. $J_{th}=0.81\text{kAcm}^{-2}$ is measured at 80K with a T_0 of 97K from 40-120K for a HR coated device.

An efficient light source monolithically integrated on a silicon substrate is one of the key components to combine the advantages of optical data processing with the mature silicon microelectronics technology. This merging of technologies is essential to keep up with the ever increasing need for bandwidth, optical inter- and intra-chip connections which are an active area of investigation within both the industrial and academic sectors of the optical-communications market. The temperature dependence and physical properties of the novel direct band-gap dilute nitride Ga(NAsP) pseudomorphically grown on GaP substrates has previously been reported [1]. The integration of Ga(NAsP) on an exactly oriented (001) silicon substrate is more challenging and requires a defect-free nucleation of GaP on silicon [2, 3]. The small lattice mismatch between GaP and silicon becomes crucial for the deposition of thicker III/V materials. However, the incorporation of small percentage of Boron (B) or Nitrogen (N) into GaP ensures the adjustment of the III/V lattice constant towards that of silicon [4].

In this work, we investigate the lasing properties and temperature dependence of monolithically integrated novel Ga(NAsP)/(BGa)P quantum well (QW) lasers on (001) silicon substrates grown by MOVPE. A small percentage of B is used to allow for the lattice-matched deposition of thick III/V separate confinement heterostructures (SCHs) and for strain compensation of the highly compressively strained Ga(NAsP) QW material for this study. Electrically injected lasing operation is observed for the first time in this novel silicon based broad-area laser up to 120K. The device performance is investigated with various device structures as shown in Table-1.

Wafer Ref.	Device Ref.	No of QW	Facets	$J_{th}(\text{kA/cm}^2)$ at 80K	λ_{lasing} (nm) at 80K	$T_0(\text{K})$ 40-120K
#16052	A	1	CL/CL	0.95	813	75
#16053	B	3	CL/CL	0.81	836	81
#15977	C	1	CL/CL	1.05	826	86
#15977	D	1	HR/HR	0.99	828	97

Table 1: Summary of device structures and performance.

The active region of devices A and B consist of a GaNAsP QW (triple for device B) within $(\text{B}_{-5\%}\text{Ga})(\text{As}_{-11\%}\text{P})/\text{GaP}/\text{Ga}(\text{N}_{-7\%}\text{As}_{-80\%}\text{P})/\text{GaP}/(\text{B}_{-5\%}\text{Ga})(\text{As}_{-11\%}\text{P})$ (20nm/3nm/5nm/3 nm/20nm) sandwiched between 50nm $(\text{B}_{-5\%}\text{Ga})(\text{As}_{-11\%}\text{P})$ and 100nm BGaAsP grading. Device C and D consist of a $(\text{B}_{-5\%}\text{Ga})(\text{As}_{-11\%}\text{P})/(\text{B}_{-5\%}\text{Ga})\text{P}/\text{GaP}/\text{Ga}(\text{N}_{-7\%}\text{As}_{-80\%}\text{P})/\text{GaP}/(\text{B}_{-5\%}\text{Ga})\text{P}/(\text{B}_{-5\%}\text{Ga})(\text{As}_{-11\%}\text{P})$ (150nm/15/3nm/5nm/3nm/15nm/150nm) QW active region. The addition of $(\text{B}_{-5\%}\text{Ga})\text{P}$ layer in device C provides strain compensation. Figure-1 shows the threshold current density (J_{th}) as a function of temperature (Figure-1(a)) and emission wavelength (λ_{lasing}) at 80K (Figure-1(b)). We find that device B exhibits lower J_{th} and longer λ_{lasing} than device A. This is consistent with the MQW devices (B) providing a lower threshold carrier density (n_{th}) and reduced quasi-Fermi level splitting compared to the SQW devices (A). Figure 2 shows the characteristic temperature (T_0) of the devices. The low T_0 values are an indication of a thermally activated recombination process such as carrier leakage as previously observed in GaNAsP/GaP lasers [1]. Auger recombination, which dominates lasers at longer wavelengths, is unlikely to be significant at the short wavelengths and low

Figure 1: J_{th} as a function of temperature (Figure-1(a)) and EL spectra (Figure-1(b)) at $\sim 1.1I_{th}$ for Ga(NAsP)/(BGa)P/Si QW lasers.

temperature considered here. The slight improvement in T_0 of device B compared to device A is consistent with reduced non-radiative recombination in the MQW devices. Devices C & D exhibit slightly higher threshold currents suggesting that the BGaP strain compensation layer requires further optimization. Device D (HR coated) exhibits a reduced threshold current and increased T_0 due to the reduction in threshold gain compared with device C. Further information about device structures, carrier recombination mechanisms and the prognosis for room temperature lasing on silicon with this approach will be discussed in more depth at the conference.

Figure 2: Natural log of I_{th} (mA) as a function of temperature (K) for Ga(NAsP)/(BGa)P/Si QW lasers.

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