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14. ABSTRACT In this work we report on design and development of the single spatial mode cascade diode lasers operating near 3.15 μm . The narrow ridge lasers generated more than 40 mW of continuous wave (CW) power at room temperature (RT) in diffraction limited beam. Each gain stage consists of three nominally 1.3%-compressively-strained Ga ₄₅ In ₅₅ As ₃₀ Sb ₇₀ quantum wells (QWs), spaced by 50 nm of quinary AlGaInAsSb barriers, and sandwiched between two 200-/250-nm-wide barrier layers of the same composition. The tunnel junction/carrier injector heterostructure was based on 100 nm thick AlGaAsSb graded layer, 10 nm thick GaSb layer and					
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Report Title

Diffraction limited 3.15 μm cascade diode lasers

ABSTRACT

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Diffraction Limited 3.15 μm Cascade Diode Lasers

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Semiconductor lasers operating in continuous wave (CW) regime at room temperature (RT) above 3 μm are in demand for spectroscopic application since many atmospheric and industrial gases, for instance, methane, ethane, acetylene, etc, have strong absorption lines in this spectral region. Compact and efficient devices emitting diffraction limited beam are prerequisite for tunable diode laser spectroscopy sources based on either distributed feedback¹ or external cavity concept². Narrow ridge waveguide GaSb-based type-I quantum well (QW) diode lasers have been reported³. Our research group had proposed and demonstrated a novel approach to enhance the power and efficiency of GaSb-based type-I QW diode lasers by utilizing cascade pumping scheme⁴. The carriers were recycled with 100% efficiency between two gain stages, resulting in twofold increase of the device slope efficiency as compared to the single stage diode lasers. Multimode cascade diode lasers with 100- μm -wide ridges demonstrated CW output power of 590 mW and power conversion efficiency above 10% at RT.

In this work we report on design and development of the single spatial mode cascade diode lasers operating near 3.15 μm . The narrow ridge lasers generated more than 40 mW of CW power at RT in diffraction limited beam. Schematic band diagram of the two-stage cascade type-I QWs diode laser heterostructure is shown in Fig. 1. Each gain stage consists of three nominally 1.3%-compressively-strained $\text{Ga}_{45}\text{In}_{55}\text{As}_{30}\text{Sb}_{70}$ QWs, spaced by 50 nm of quaternary AlGaInAsSb barriers, and sandwiched between two 200-/250-nm-wide barrier layers of the same composition. The tunnel junction/carrier injector heterostructure was based on 100- μm -thick AlGaAsSb graded layer, 10-nm-thick GaSb layer and moderately doped 25-nm-wide chirped AlSb/InAs superlattice⁴.

The laser heterostructure was grown by solid-source molecular beam epitaxy. Two types of the devices were fabricated, namely, wet etched broad ridge (~100- μm -wide) multimode and dry etched narrow ridge (~6- μm -wide) single spatial mode lasers.

Light-current-voltage characteristics of the uncoated, 1-mm-long 100- μm -wide multimode devices were measured in pulsed regime at 17 °C (Fig. 2). Twofold increase of slope efficiency as compared to the reference single stage lasers was observed. With the internal optical loss of 9 cm^{-1} measured by Hakki-Paoli method, the internal efficiency at RT was estimated to be ~120%. This confirmed the carriers recycling by the cascade pumping.

The narrow ridge 6- μm -wide waveguides were defined by inductively coupled plasma (ICP) reactive ion etching (RIE) technique using chlorine-based process with Si_3N_4 mask (Fig. 3). The devices demonstrated stable single spatial mode operation with a ~11° full-width-at-half-maximum (FWHM) on slow axis and ~67° FWHM on fast axis far-field pattern at different pumping currents (Fig. 4). The single lobe Gaussian-like far-field patterns observed in both fast and slow axis directions indicated that devices were emitting diffraction limited beam.

Narrow ridge devices with 2-mm-long cavities were coated anti-/high-reflection (AR 5%/HR 95%) and mounted epi-side down with indium on gold-plated copper heatsink for CW characterization (Fig. 5). CW output power of 42 mW was achieved at 17 °C, more than a fourfold improvement as compared to the previously reported 9 mW obtained with 3.15 μm diode lasers⁵.

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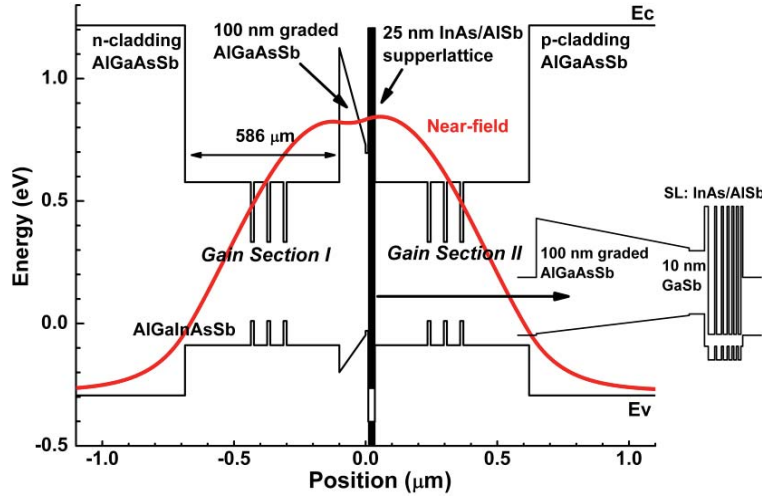


Fig.1 Schematic band diagram of the laser heterostructure in flat band condition and the calculated fundamental mode. The inset shows the details of the electron/hole injector design.

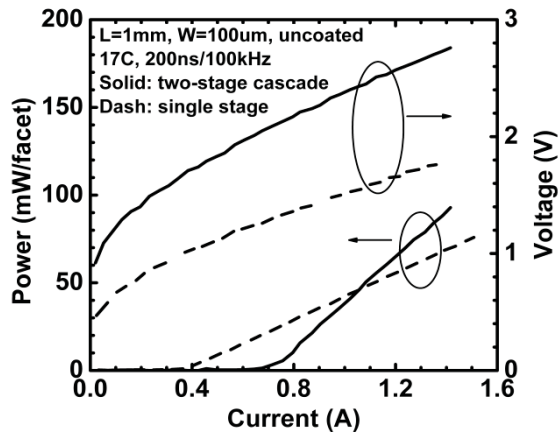


Fig.2. Light-current-voltage characteristics measured at 17 °C in short pulse regime (200 ns/100 kHz) for 100-μm-wide, 1-mm-long, uncoated 3.1 μm two-stage cascade (solid line) and reference single stage (dash line) lasers.

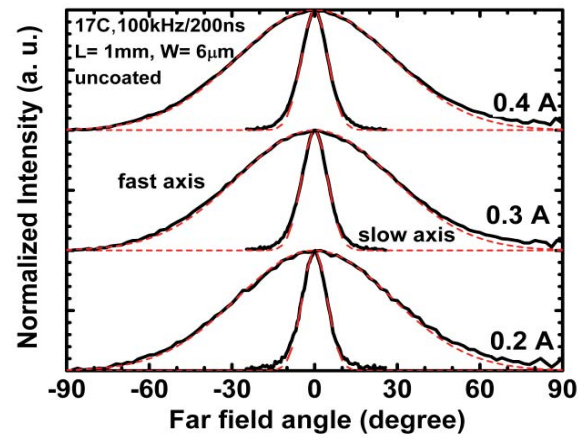


Fig.4. Fast and slow axis far-field pattern (solid lines) of narrow ridge two-stage cascade diode lasers (epi-up mounted) measured at different currents at 17 °C. The dash lines are the Gaussian fit.

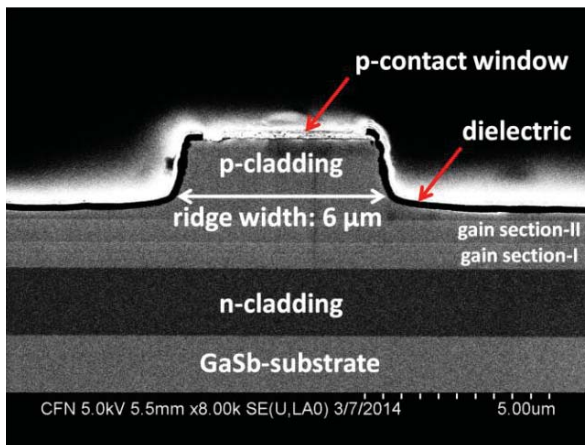


Fig.3. SEM image of the as cleaved mirror of the narrow ridge waveguide diode laser.

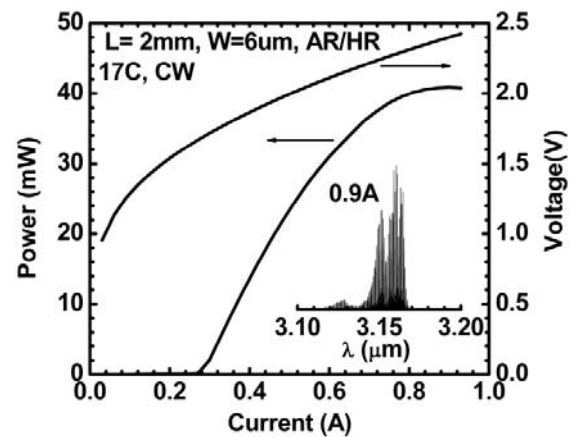


Fig.5. CW power-current-voltage characteristics of 2-mm-long AR/HR narrow ridge lasers at 17 °C (inset shows the emission spectra at 0.9 A).