Current-injection lasing in T-shaped GaAs/AlGaAs quantum-wire lasers

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Abstract. Current-injection T-shaped GaAs/AlGaAs quantum wires lasers have been fabricated by a cleaved-edge overgrowth method with molecular beam epitaxy. Continuous single-mode operation at photon energy of ~1.5 eV has been demonstrated between 30 K up to 70 K from laser diodes with high-reflectivity coating on both cleaved facets. The lowest threshold current (I_{th}) of 0.27 mA has been achieved at 30K, which are attributed to the high quality of the 2D confined structure and hence very low internal losses of the optical cavities.

Keywords: Quantum wire lasers, Low threshold current
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INTRODUCTION

The quantum-wire lasers are expected to operate efficiently with low injection currents. Intensive experimental efforts have been made to verify and understand such low threshold current. Nevertheless, the physics arguments are still unclear, because threshold currents are determined not only by the optical and material properties of quantum wires, but also by the design of optical waveguide and cavity, and by the electrical properties of the laser devices. Further experiments are necessary on quantum-wire-laser samples with high controllability in material, optical, and electrical structures. In this work, we demonstrate low-threshold singe-mode lasing in 20-period T-shaped quantum wire (T-wire) lasers with high material quality and a new efficient current injection scheme.

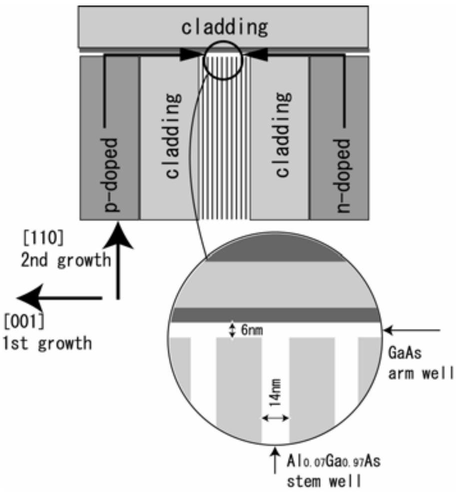

FIGURE 1. Schematic cross-sectional view of a T-wire laser structure. The arrows at the upper panel indicate the carrier injection from the doped layer to T-wire active region via the arm well.

EXPERIMENT

Current-injection T wire lasers were fabricated by the cleaved-edge overgrowth method with molecular beam epitaxy (MBE)[1]. Figure 1 shows a schematic view of the laser structure. The quantum wires were formed at the T-intersections of 20-period 14-nm-thick (001) $Al_{0.07}Ga_{0.97}As$ multiple quantum wells (MQWs) (stem wells) and a 6-nm-thick (110) GaAs quantum well (arm well). Laser bars of 500 µm cavity length were cut from the wafer by cleavage with the cleaved facets perpendicular to the axis of the T-wires after MBE growth and metallization. The cavity facets were coated by high reflectivity Au-layers after deposition of 70 nm SiO_2 insulating layer with plasma-assisted chemical vapor deposition.

By this injection scheme, both electrons and holes are injected into the active region of 20 T-wires via only the arm well, i.e. the current is well defined in the thin arm well, as shown by the arrows in the upper panel. Light emission from the laser diode was dispersed in a 0.75-m spectrometer and detected with a charge-coupled-device (CCD) camera. A photodiode detector was used to measure the output power.

RESULTS AND DISCUSSION

Figure 2 shows the current versus voltage (I-V) curve of the laser diode at temperatures from 5K to room temperature (r.t.), exhibiting typical diode characteristic. The soft turn-on of the I-V curve at temperatures below 30 K is probably due to carrier freezing in doped MQW and buffer layers. Figure 3 shows the single facet light output power characteristics for a 500 μm length laser diode as a

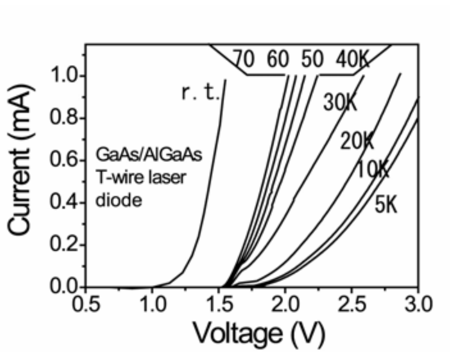

FIGURE 2. Diode current-voltage characteristics of a T-wire laser at various temperatures from 5K to room temperature (r.t.) indicated in the figure.

function of the bias current at 30 K, together with the output spectra at four different bias points below and above threshold, respectively. The threshold current (I_{th}) of the laser device is 0.27 mA and the mean differential quantum efficiency is 12% at 30K. The optical spectrum is modulated by Fabry-Pérot oscillations below the threshold current and turns into a single lasing mode at 1.554 eV after the current reaches the threshold current. The largest shift as the current increases to 1.5 mA is 1.2 meV, showing the stability of the lasing energy from our T-wire lasers. No emission or lasing from the stem wells has been observed at all injection currents investigated, indicating high injection efficiency. Single-mode lasing has been similarly observed at the cryostat temperatures between 30 and 70 K. If we assume internal quantum efficiency $\eta_i = 1$ on the basis of high injection efficiency and negligibly small nonradiative decay, the measured η_d of 12% at 30 K gives an estimation of internal loss $\alpha_i = 0.32\ cm^{-1}$. The I_{th} of 0.27 mA at 30 K for 20 T-wires corresponds to 0.014 mA per 500-μm-long single-wire. Thus the threshold carrier density is estimated to be $7x10^5\ cm^{-1}$ per single-wire by using separately measured carrier lifetime of 0.4 ns and the assumed $\eta_i = 1$. This estimated result agrees well with our separate experimental results on optically pumped T-wire lasers [2-5].

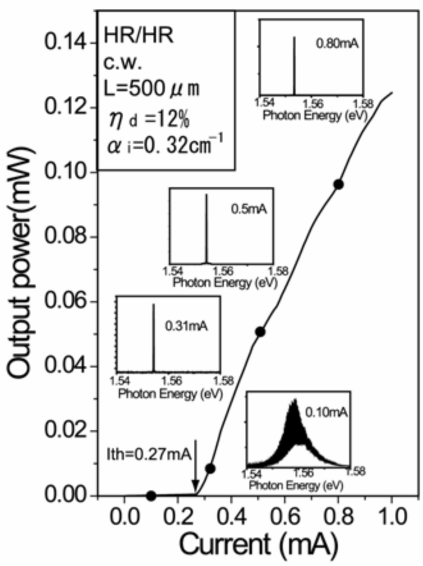

FIGURE 3 Light power–current characteristics and emission spectra at different bias currents for a high-reflection (HR) coated T-wire laser diode under c.w. operation at 30K. The threshold current (Ith), the estimated differential quantum efficiency (η_d) and internal loss (α_i) has been indicated in the figure.

SUMMARY

We have presented low-threshold current-injection lasers using 20-period T-wires of high material quality as gain medium and a simple but efficient current injection scheme, which contribute to the low threshold current and hence low threshold current density and low internal loss in our c.w. operated laser diodes.

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