Ground state lasing in a high quality single quantum wire

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Ground state lasing with a single quantum wire in the 1-D quantum limit is realized for the first time by the cleaved-edge overgrowth method, which contains only one quantum wire with only one 1-D quantized electronic state.

Figure 1 shows a schematic cross-sectional view of the single-wire laser structure optimized by finite-element-method calculation. It is fabricated by the cleaved-edge overgrowth method with MBE [1,2], in which two MBE growth steps are separated by an *in situ* wafer cleavage process. At the T-intersection of a 14nm $Al_{0.07}Ga_{0.93}As$ well (stem well) and a 6nm GaAs well (arm well), a T-shaped quantum wire (T-wire) is formed. It is embedded in a core of T-shaped optical waveguide (T-waveguide) formed by two 250nm $Al_{0.35}Ga_{0.65}As$ layers and a 111nm $Al_{0.1}Ga_{0.9}As$ layer. We introduced *in situ* annealing at 600 °C for 10 minutes after the growth of the arm well, that dramatically improved its uniformity [3]. A laser bar with 500μm optical cavity was cut from the wafer by cleavage, and the cavity-mirror surfaces were coated by 120nm- and 300nm-thick gold with estimated reflectivity of about 97%.

Lasing performance of the single-wire laser was measured by optical pumping with cw titanium-sapphire-laser light, mechanically chopped into 1% duty ratio to minimize sample heating. Excitation light energy was 1.645eV. Lasing due to T-wire was observed for 5-60 K at energy of the T-wire ground state. Figure 2 plots laser emission intensity of T-wire at 5K against input power up to 260 mW, and the inset shows magnified plots near lasing threshold. The threshold power was as low as 5 mW at 5 K. In Fig. 2, we also plot intensities of respective longitudinal modes P1-P5 of T-wire lasing that will be shown in Fig. 4. Switching among these lasing modes explains several dips in the total emission intensity of T-wire lasing.

Figure 3 shows lasing spectra at 5 K measured with the spectral resolution of 0.2 meV. Lasing lines due to T-wire, arm well, and stem well are observed. T-wire has fewer longitudinal modes than the arm and stem wells. Figure 4 shows magnified spectra of T-wire, where longitudinal modes P1-P5 are denoted. While input power is low, T-wire shows multi-mode lasing with several longitudinal modes. As input power is increased, lasing modes become fewer and red-shifted. Note that red-shift of stimulated emission peak was as small as 2 meV in spite of wide variation of the input power. Lasing-mode separation is $\Delta E_1 = 0.68$ meV below input power of 130 mW, while it becomes $\Delta E_2 = 0.34$ meV above it.

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[2] W. Wegscheider, et al., Phys. Rev. Lett. **71**, 4071-4074 (1993).
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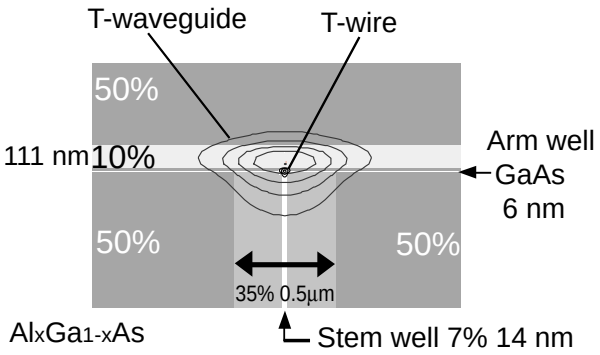

Figure 1: Schematic cross-sectional view of a single-wire laser structure optimized by finite-element-method calculation. Percentages show Al-concentration x in $Al_xGa_{1-x}As$. A T-shaped quatum wire is formed at T-intersection of a stem well and a arm well, and embedded in a core of T-shaped optical waveguide.

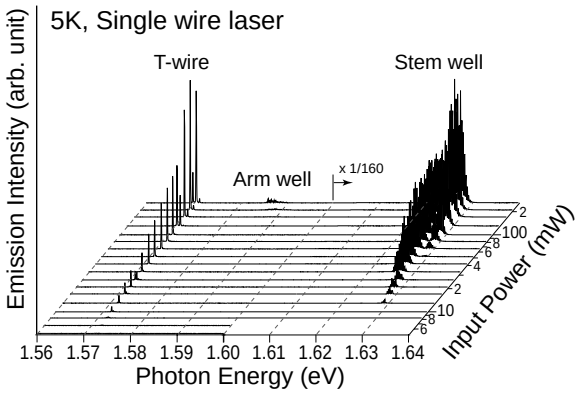

Figure 3: Lasing spectra at 5 K for various input power up to 260 mW measured with spectral resolution of 0.2 meV. Lasing lines due to T-wire, arm well, and stem well are observed.

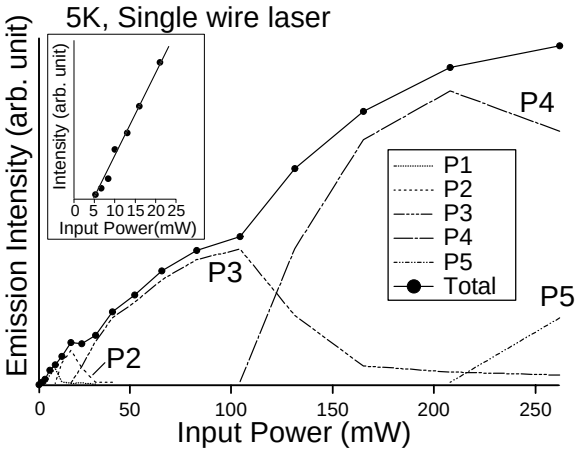

Figure 2: Laser emission intensity of T-wire at 5K against input power up to 260 mW. The inset shows magnified plots near lasing threshold. P1-P5 indicate intensities of respective longitudinal modes of T-wire lasing, and "Total" is the sum of P1-P5.

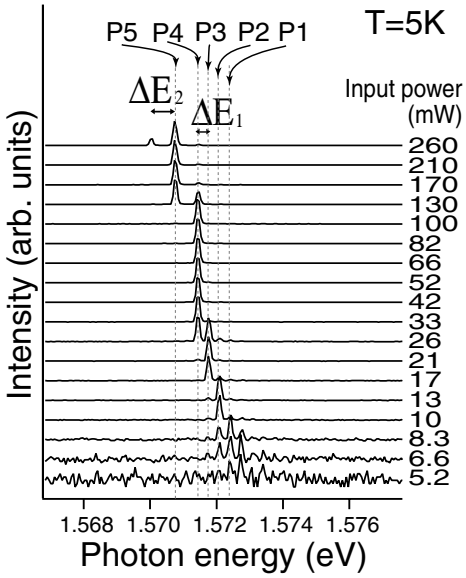

Figure 4: Magnified spectra of T-wire. Longitudinal modes are denoted by P1-P5, where mode separation is $\Delta E_1 = 0.34$ meV below input power of 130 mW, while it is $\Delta E_2 = 0.68$ meV above it.