Low-threshold T-shaped Quantum Wire Lasers by Arm-arm Current Injection

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- Characteristics of our low threshold lasers, including

  arm-arm current injection scheme;

  emission spectra and images;

  I-L and I-V curves.
- Summary

Introduction

- Why low threshold?

LOW THRESHOLD lasers are attractive for optical communication systems because of the **tight packing density, low power consumption** and **high modulation bandwidth.**

- How to get low-threshold?

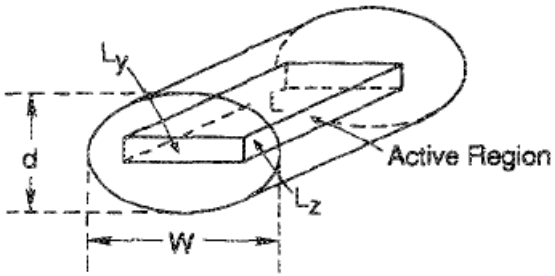
Ideal QUANTUM WIRE lasers are predicted to show ultralow threshold current of several μA due to small volume of active region and large density of states at the subband edges.

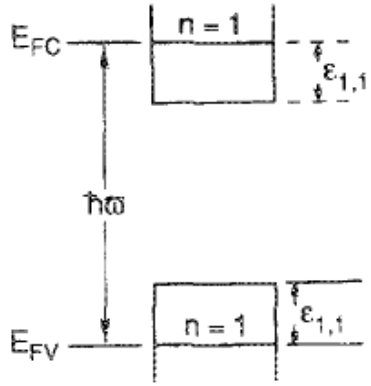
Theoretical threshold current for 3,2,and 1D system (A. Yariv APL 53, 1033 (1988))

$$(I_{th})_{3D}\left(\frac{\eta\tau}{e}\right) = N_{3D}^{tr}(WL_zL) + \left(\frac{Wd}{g'_{3D}}\right)\ln R^{-1} + \frac{(WLd)}{g'_{3D}}\alpha_{scatt}$$

$$(I_{th})_{2D}\left(\frac{\eta\tau}{e}\right) = N_{2D}^{tr}(WL) + \frac{(Wd)}{g'_{2D}}\ln R^{-1} + \frac{(WLd)}{g'_{2D}}\alpha_{scatt}$$

$$(I_{th})_{1D}\left(\frac{\eta\tau}{e}\right) = N_{1D}^{tr}L + \frac{(Wd)}{g'_{1D}}\ln R^{-1} + \frac{(WLd)}{g'_{1D}}\alpha_{scatt}$$





In which, the transparency carrier density

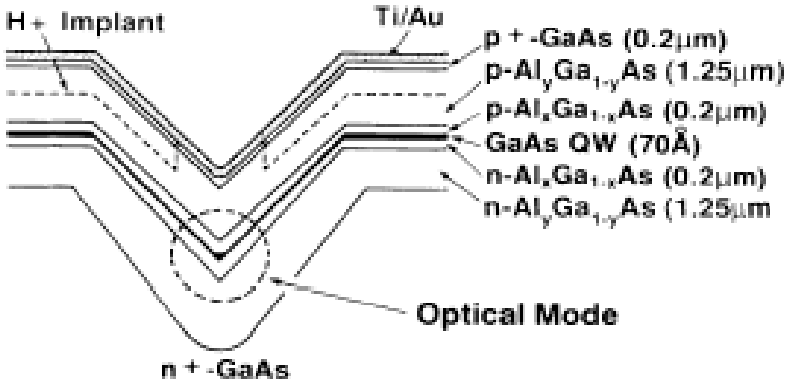
$$N_{3D}^{tr} \sim 1.5\times10^{18}\ \mathrm{cm}^{-3},$$
$$N_{2D}^{tr} \sim 1.5\times10^{12}\ \mathrm{cm}^{-2},$$
$$N_{1D}^{tr} \sim 1.5\times10^{6}\ \mathrm{cm}^{-1}.$$

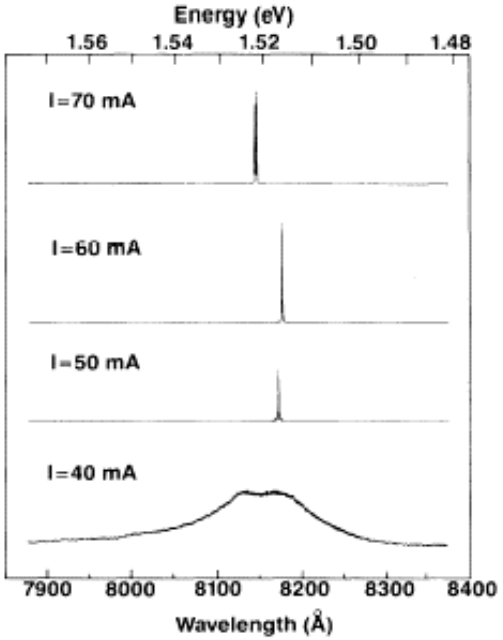
Assuming infinite potential well depth;
Involving only the first quantized states.

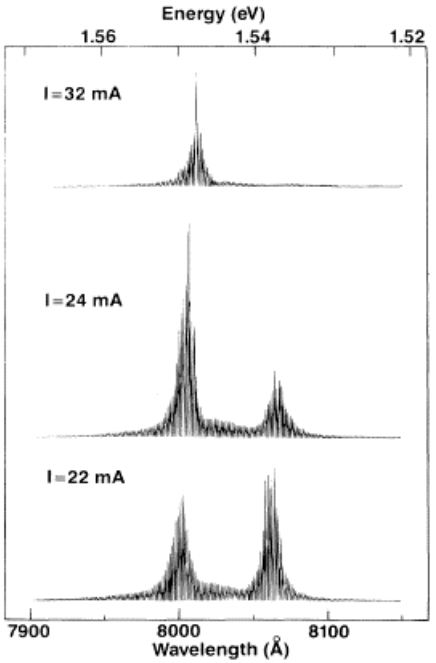
Quantum well lasers: 100 μA; **Quantum wire lasers**: 2-3 μA.

Previous experimental results I (V-groove)

V-groove quantum wire lasers grown on patterned substrates





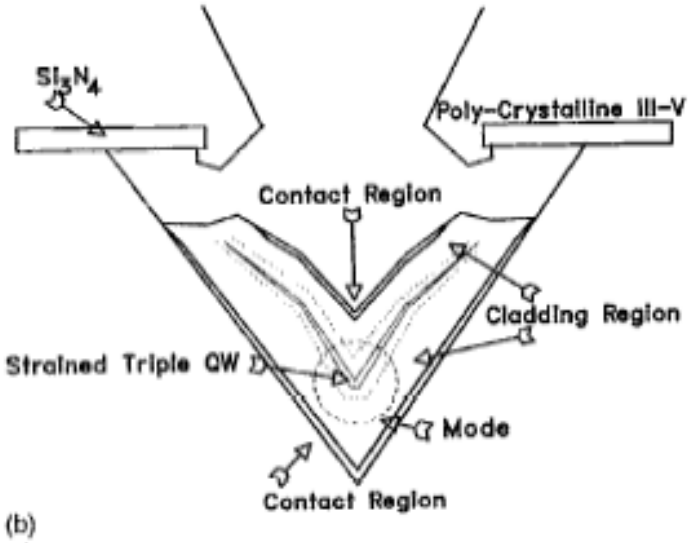


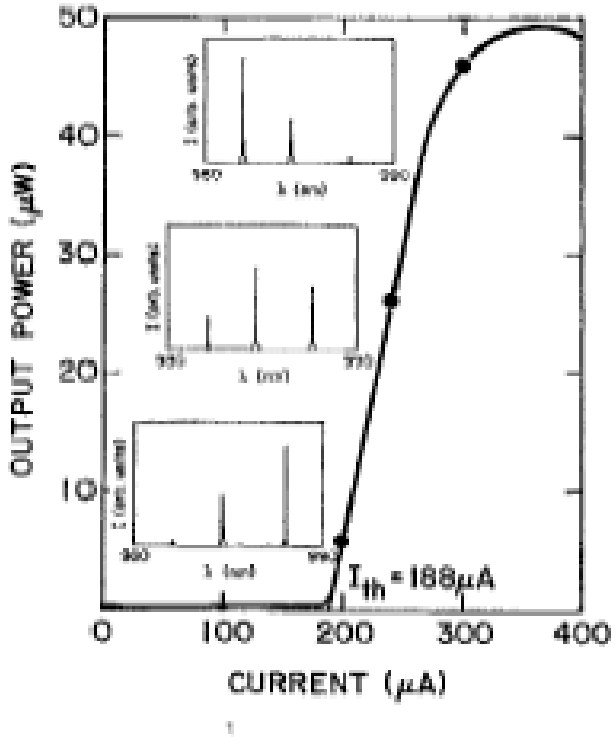
V-groove QWRs
9 nm X 80-100 nm
I_{th}=50 mA

1989: Kapon et al, Phys. Rev. Lett. 63, 430

Previous experimental results II (V-groove)

Lowest threshold current of V-groove quantum wire lasers



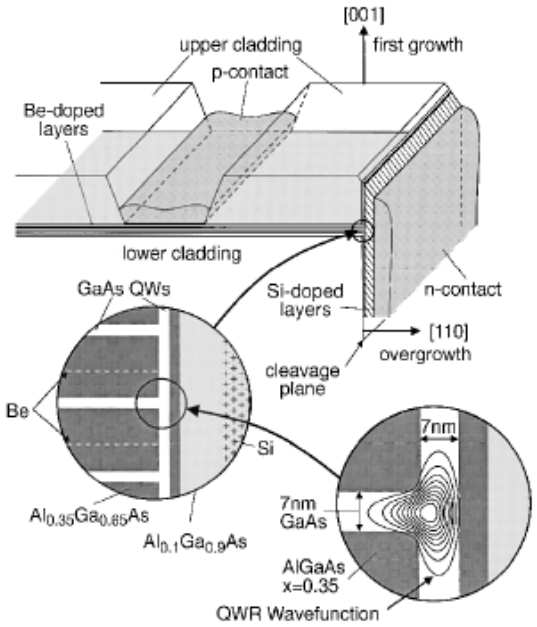


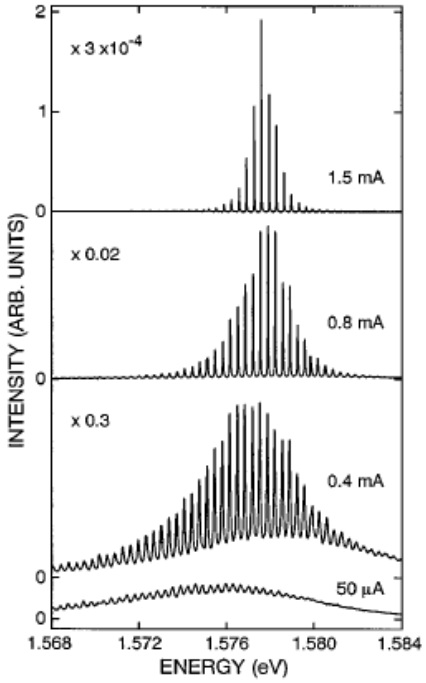
3-period V-groove QWRs with Si_3N_4 mask
10 nm X 35 nm
I_{th}=0.19 mA

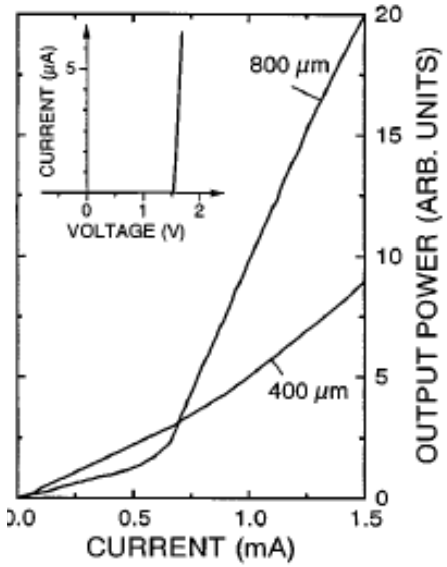
1994: Tiwari et al, Appl. Phys. Lett. 64, 3536

Previous experimental results III (T-shaped)

T-shaped quantum wires provide smaller size and higher array density



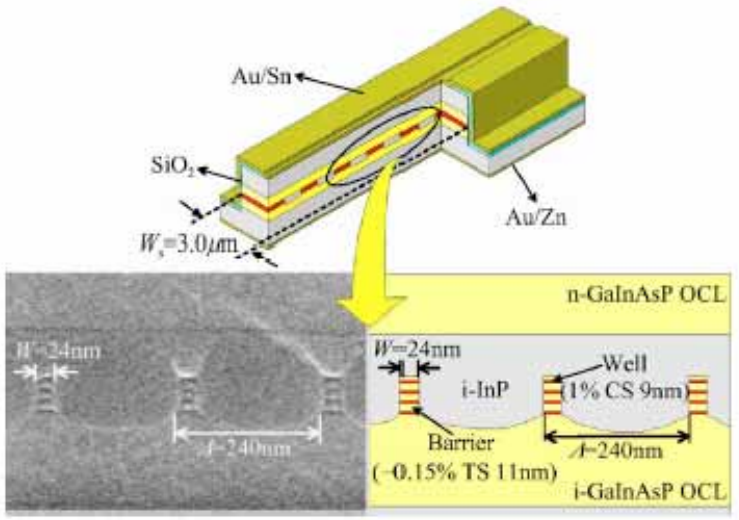


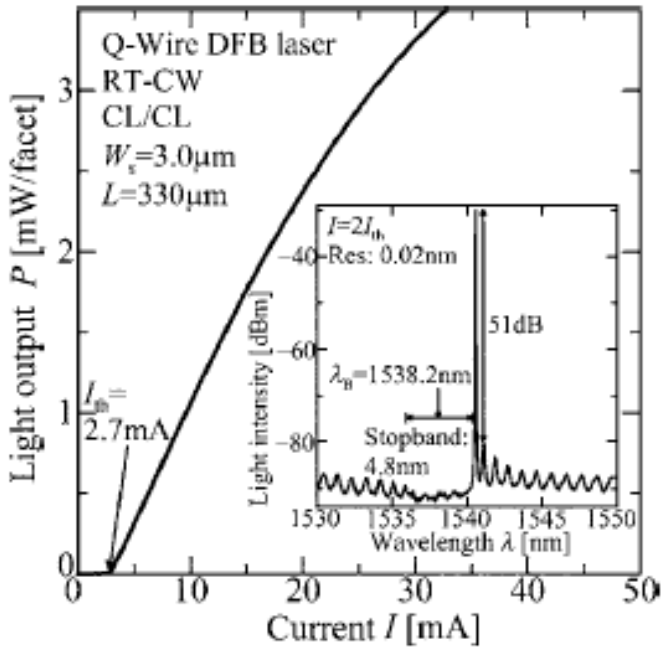


15-period 7 nm X 7nm T-wires
I_{th}=0.4-0.7 mA @ 4K

1994: Wegscheider et al, Appl. Phys. Lett. 65, 2510

Previous experimental results IV (DFB)

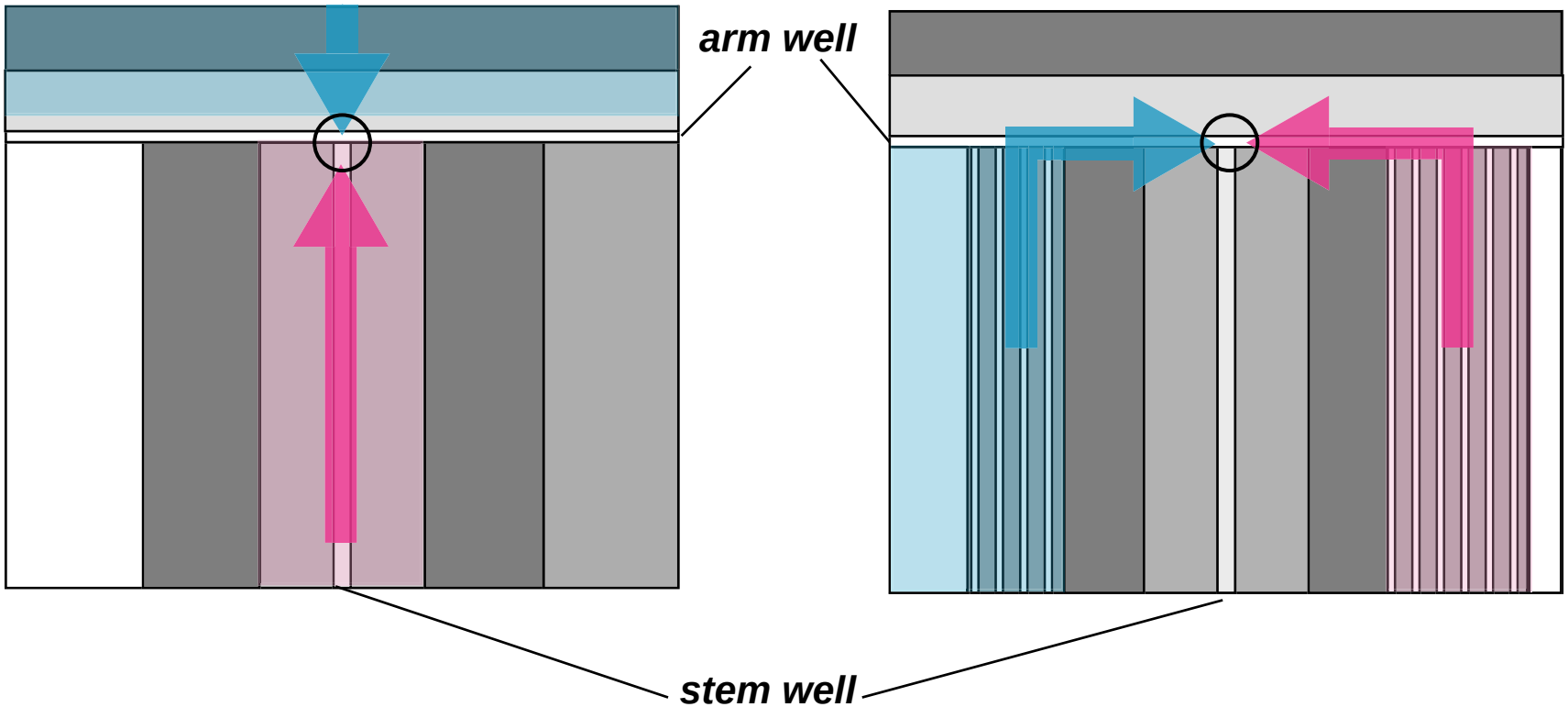




InGaAsP/InP QWR DFB laser
9 nm x 24 nm
EB lithography, dry and wet etching, MOCVD growth
cw 1.5 μm-wavelength lasing
I_{th}= 2.7 mA @ r.t.

2005: Yagi et al, Appl. Phys. Lett. 87, 223120

Current injection schemes of T-wire lasers

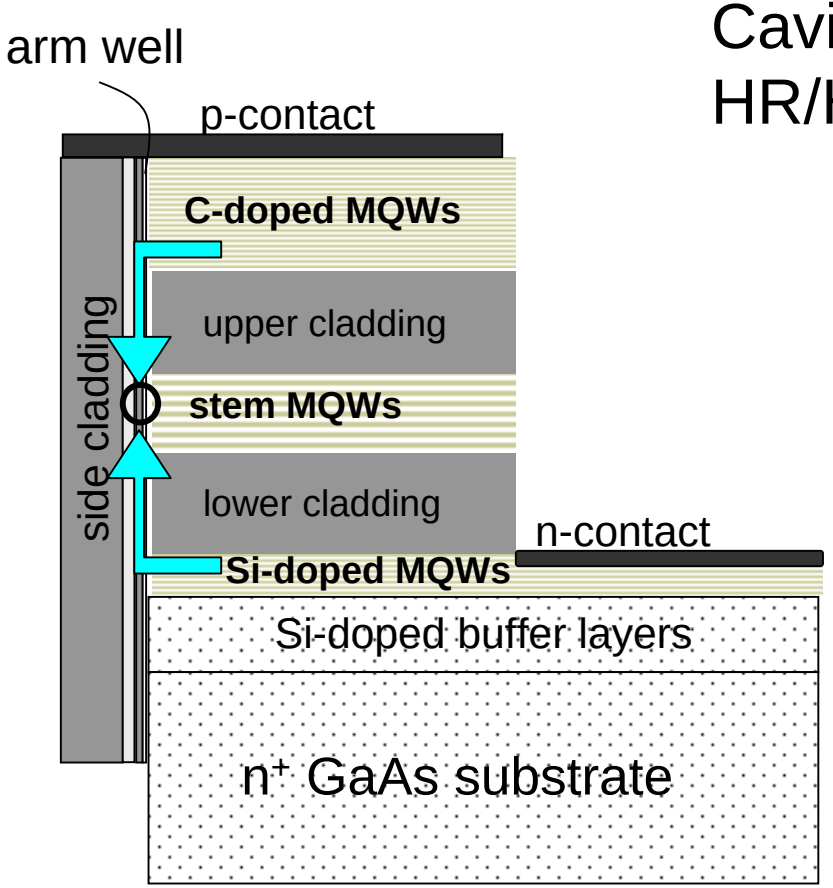


arm-stem injection

arm-arm injection

24aXL-12 Okano et al.

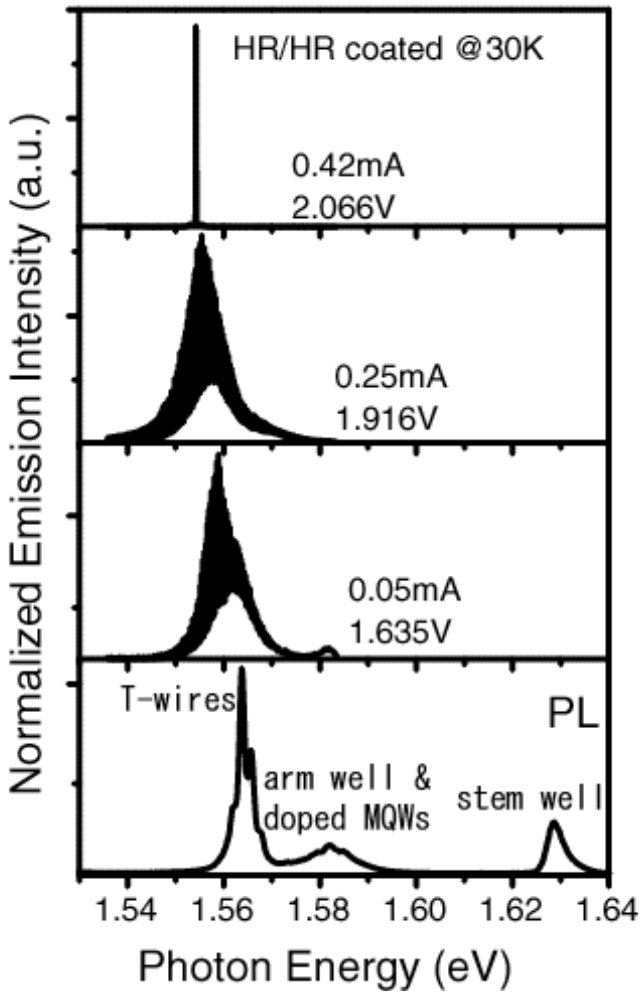
MBE growth of arm-arm injection laser



Cavity length: 500 μm
HR/HR coating by Au(300nm/50nm)

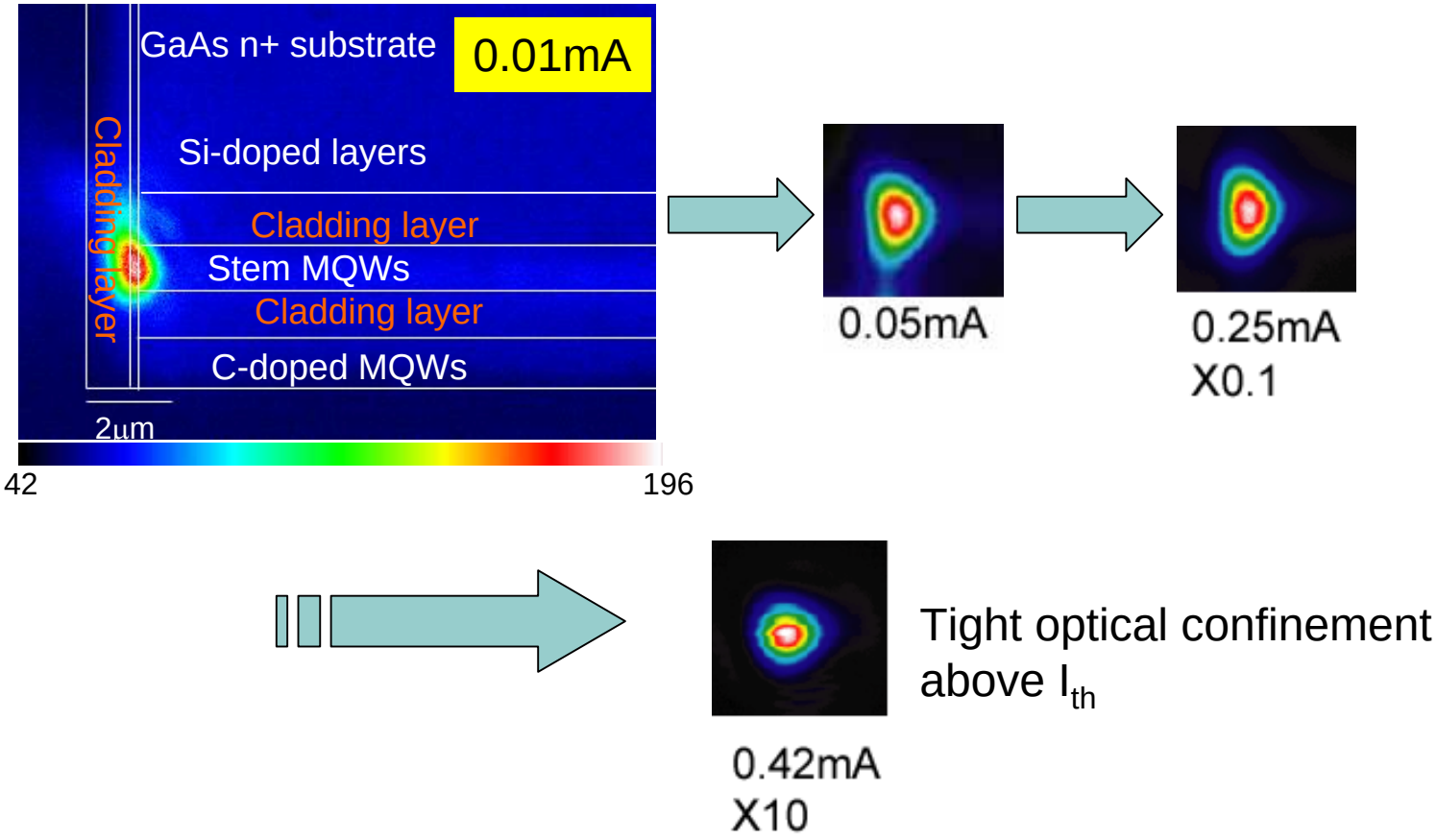
Current confinement
in the single arm well

EL and lasing spectra @ 30K

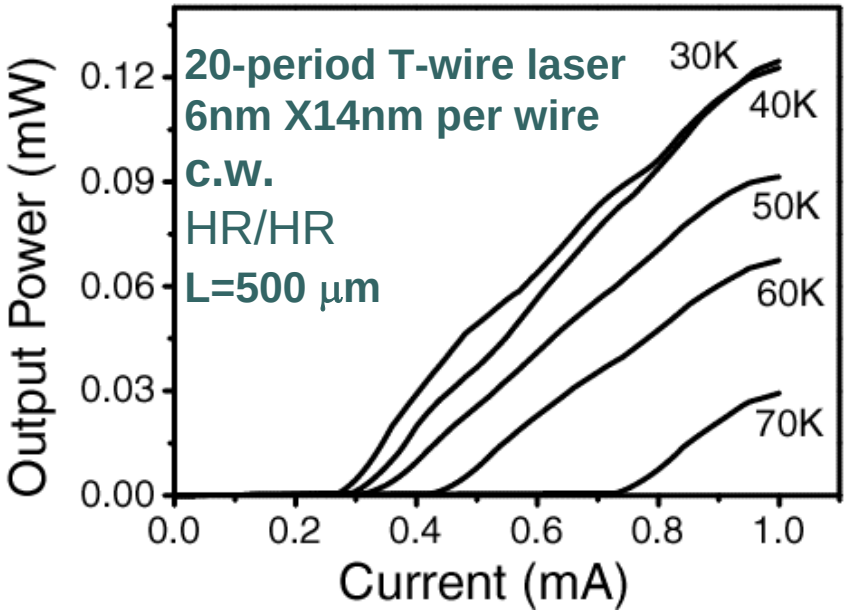


- No EL or lasing from stem well indicating current confinement in the arm well;
- Single mode lasing above threshold;
- Similar spectra from 30-70K.

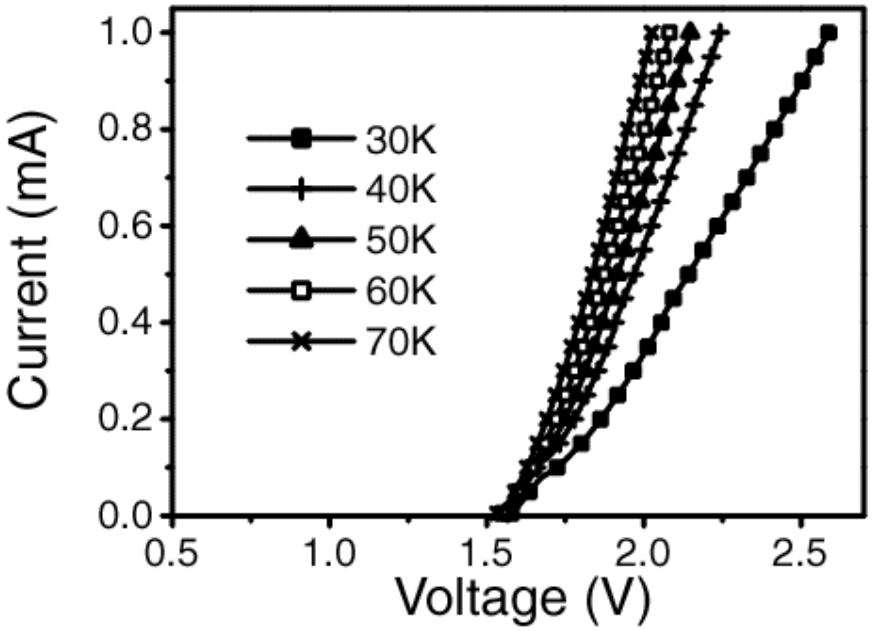
EL images @ 30K



Power out & voltage vs current

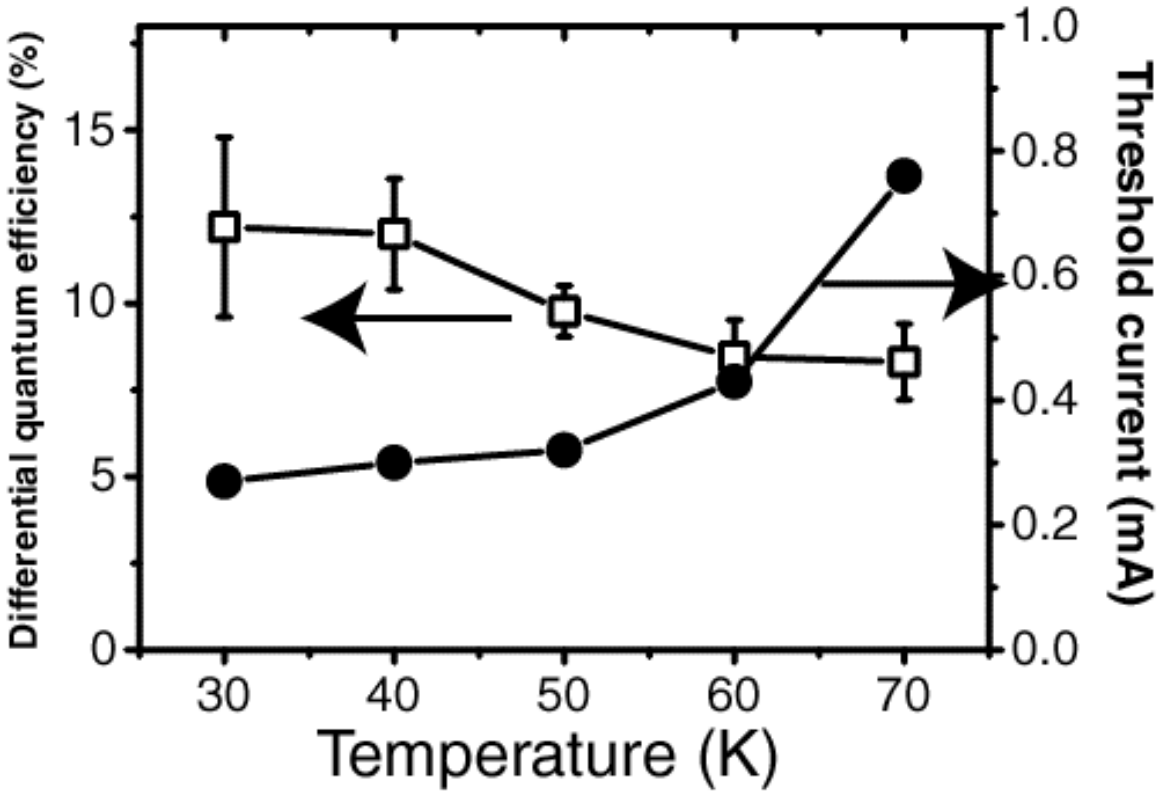


I-L



V-I

Temperature dependence



Threshold current: 0.27-0.76 mA
Differential quantum efficiency: 12%-8.2%

Summary

- Arm-arm injection scheme makes current confinement in the single arm well;
- A very low threshold current of 0.27 mA has been achieved @ 30K from a 500 μm device under cw operation;

Lasing mechanism will be presented by

Dr. Yoshita 24aXL-11