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**PERFORMANCE COMPARISON OF OPTICALLY  
PUMPED TYPE-II MID-INFRARED LASERS  
(Briefing Charts)**

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<b>14. ABSTRACT</b> We report a comparative study on the performance of three optically pumped, type-II quantum well lasers with differing quantum well confinement. One of the active regions emphasized hole confinement, another emphasized electron confinement, while the third incorporated both electron and hole confinement. In all cases the wells were inserted in a thick $\text{In}_x\text{Ga}_{1-x}\text{As}_y\text{Sb}_{1-y}$ waveguide/absorber region. The lasing wavelengths at 84 K were 2.26 $\mu\text{m}$ , 3.44 $\mu\text{m}$ , and 2.37 $\mu\text{m}$ , respectively. The maximum peak output powers and differential quantum efficiencies, $\eta$ , at 84 K were similar for the hole well and W lasers ( $\approx 13$ W, $\eta \approx 0.55$ ), but significantly reduced in the electron well only laser (2.3 W, $\eta = 0.14$ ). Waveguide loss measurements via the traditional quantum efficiency vs. cavity length method and by a Hakki-Paoli method revealed that all three lasers had low waveguide loss that either increased slowly or not at all with increasing temperature. However, the laser's internal efficiency, $\eta_i$ , showed a linear decline with increasing temperature, with the $\eta_i$ of the electron well only laser significantly less than the other two. The data suggests that for antimonide based type-II designs, strong hole confinement is essential for improved performance. The data further suggest that it is hole leakage from the QW and/or hole dilution that is largely responsible for the degradation in laser performance.
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# Performance comparison of optically pumped type-II mid-infrared lasers.

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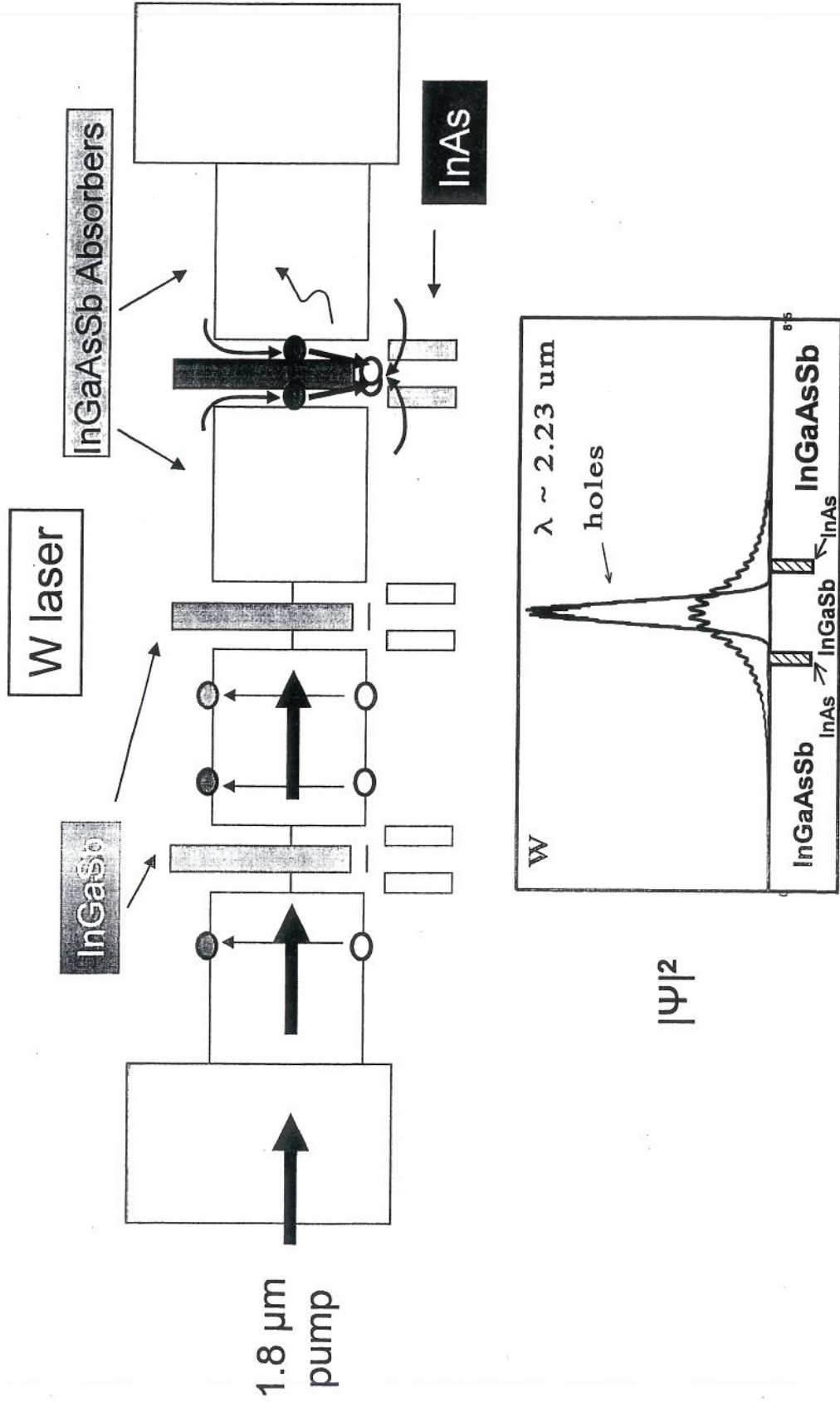
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# Objective

Compare performance of quantum well lasers with different carrier confinement.

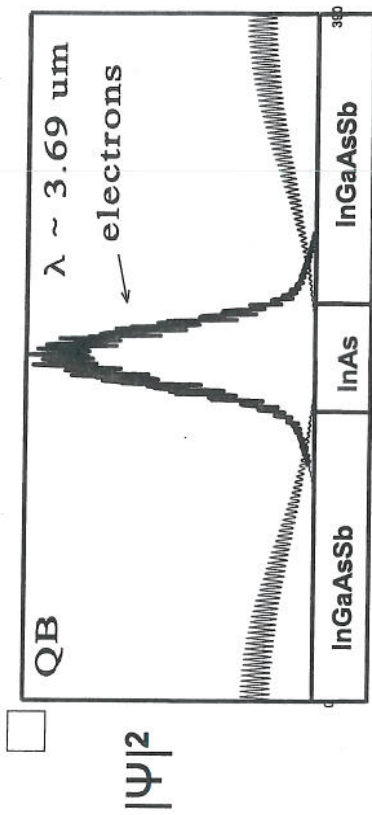
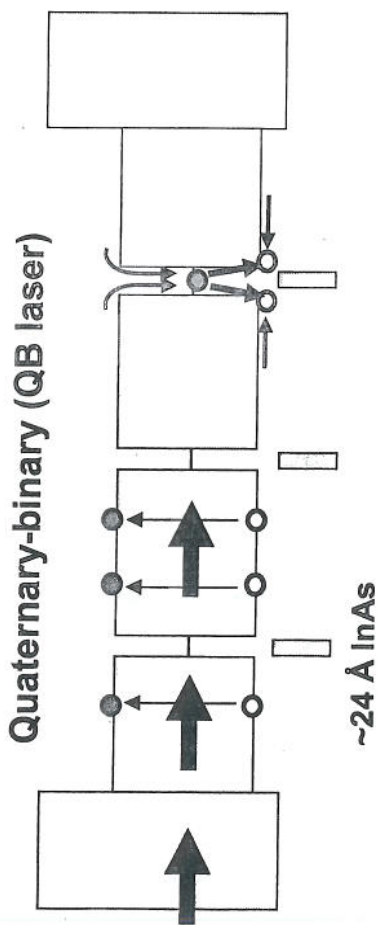
- 1) A  $\sim 24 \text{ \AA}$  thick  $\text{In}_{0.35}\text{Ga}_{0.65}\text{Sb}$  hole-bearing layer sandwiched by two thin  $\text{InAs}$  coupled electron wells. This is a  $W$  laser with both electron and hole confinement.



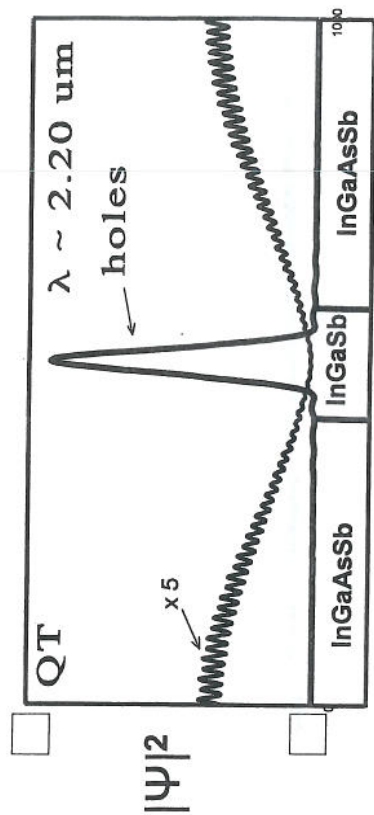
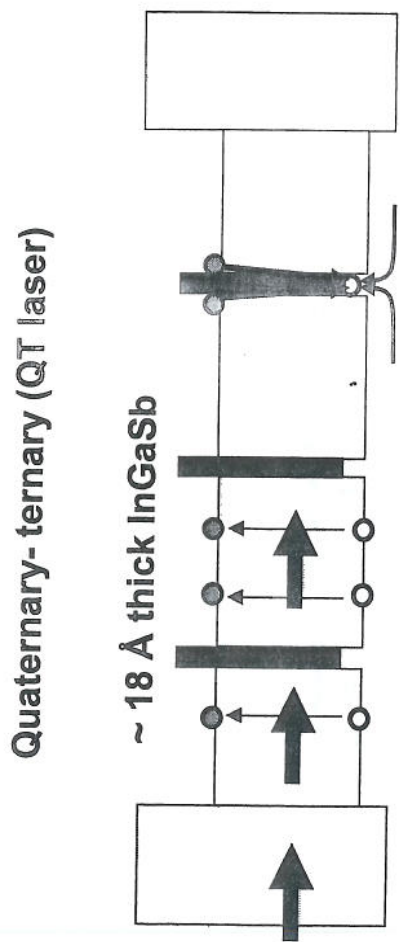
# Objective:

Compare performance of quantum well lasers with different carrier confinement.

2) A  $\sim 24 \text{ \AA}$  thick InAs electron-bearing layer. This is a laser structure with *no deliberate hole confinement*.



3) A  $\sim 18 \text{ \AA}$  thick  $\text{In}_{0.35}\text{Ga}_{0.65}\text{Sb}$  hole bearing layer. This is a laser structure with *no deliberate electron confinement*.



# Spectra & peak output power at 84 K

We observe significantly lower power output from the laser when the holes are not confined.

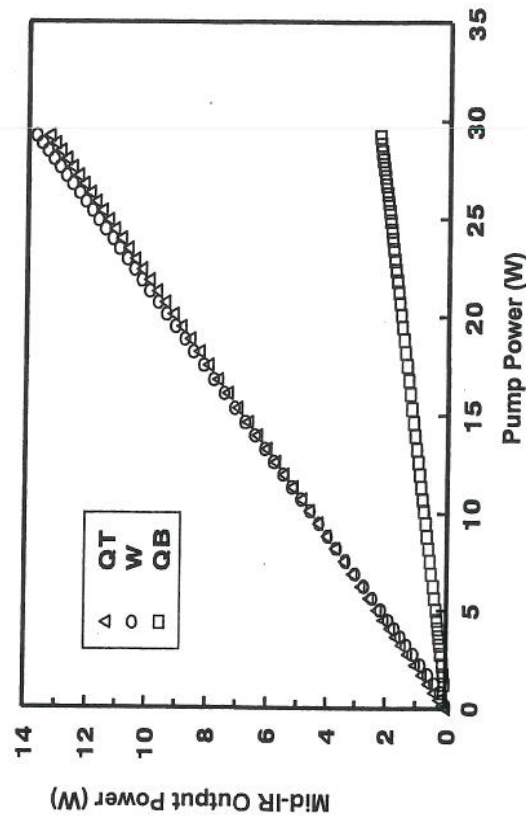
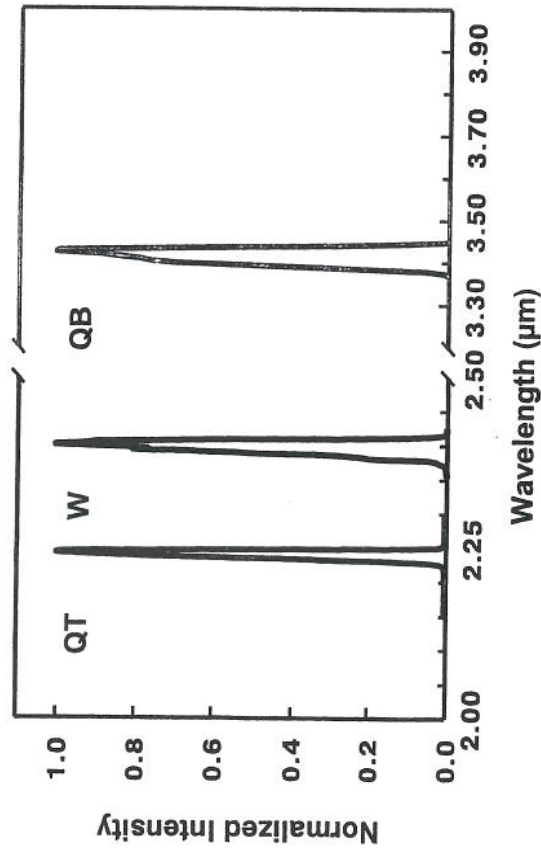
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$$\lambda_{\text{QT}} = 2.26 \text{ } \mu\text{m}, P_{\text{QT}} = 13.3 \text{ W}$$

$$\lambda_{\text{QB}} = 3.44 \text{ } \mu\text{m}, P_{\text{QB}} = 2.3 \text{ W}$$

$$\lambda_{\text{W}} = 2.26 \text{ } \mu\text{m}, P_{\text{W}} = 13.7 \text{ W}$$

$$\text{FW}_{1/e}^2 \sim 5.3 \text{ meV}$$

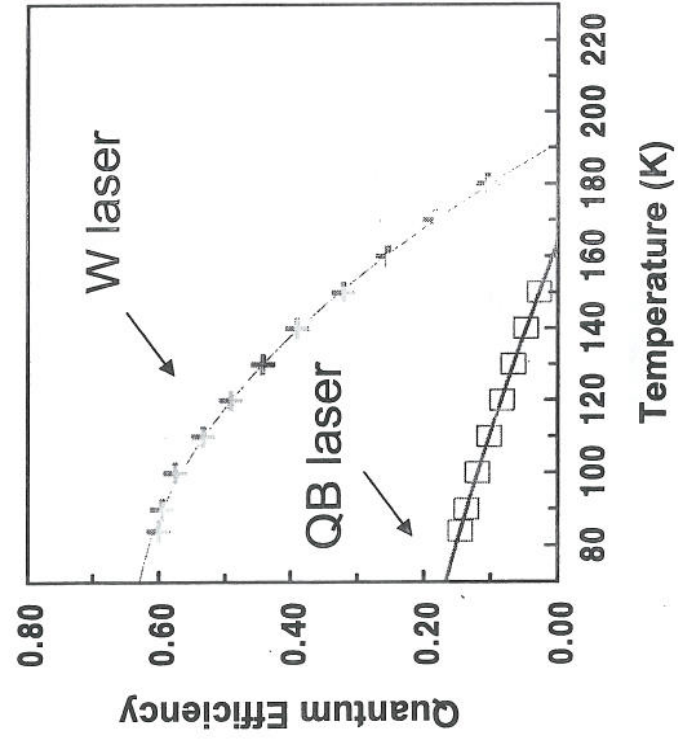


# Confining electrons vs. confining holes.

We observe good high temperature operation when confining holes, but device performance is poor if only the electrons are confined. But why?

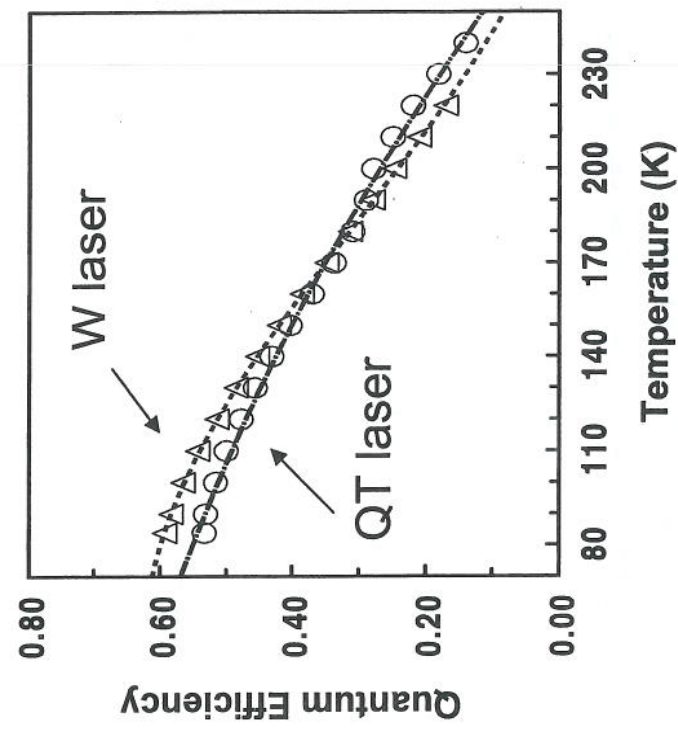
What if we only confine electrons?

3.4  $\mu\text{m}$  emitters



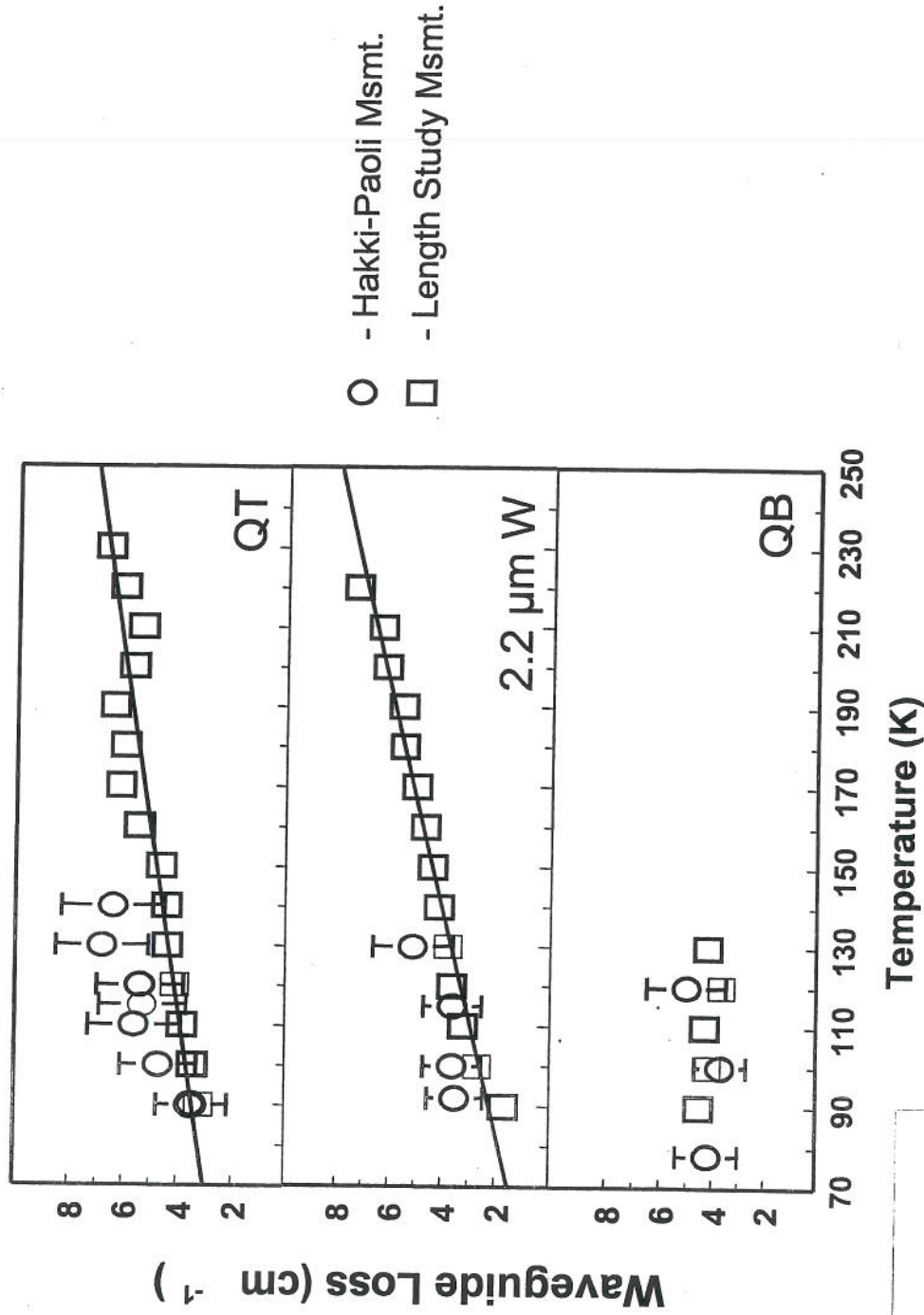
What if we only confine holes?

2.2  $\mu\text{m}$  emitters



# Does high waveguide loss account for the differences ?

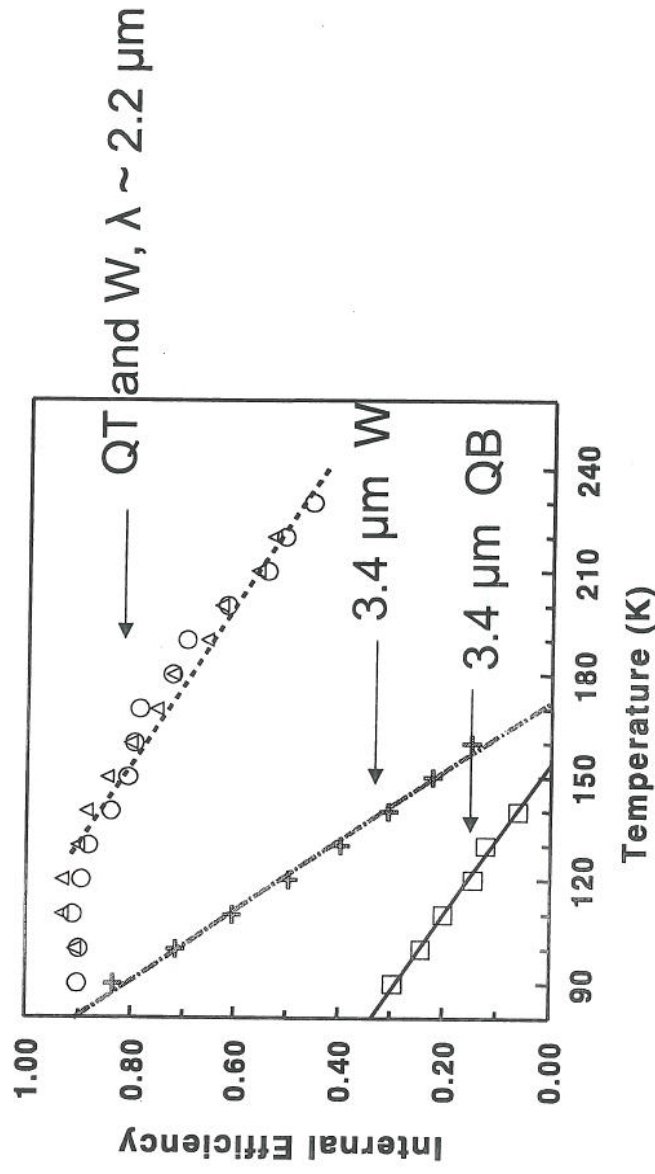
No. We observe low waveguide loss and conclude degradation via intravalence band absorbance and free carrier absorbance is small.



# Does low internal efficiency account for the differences ?

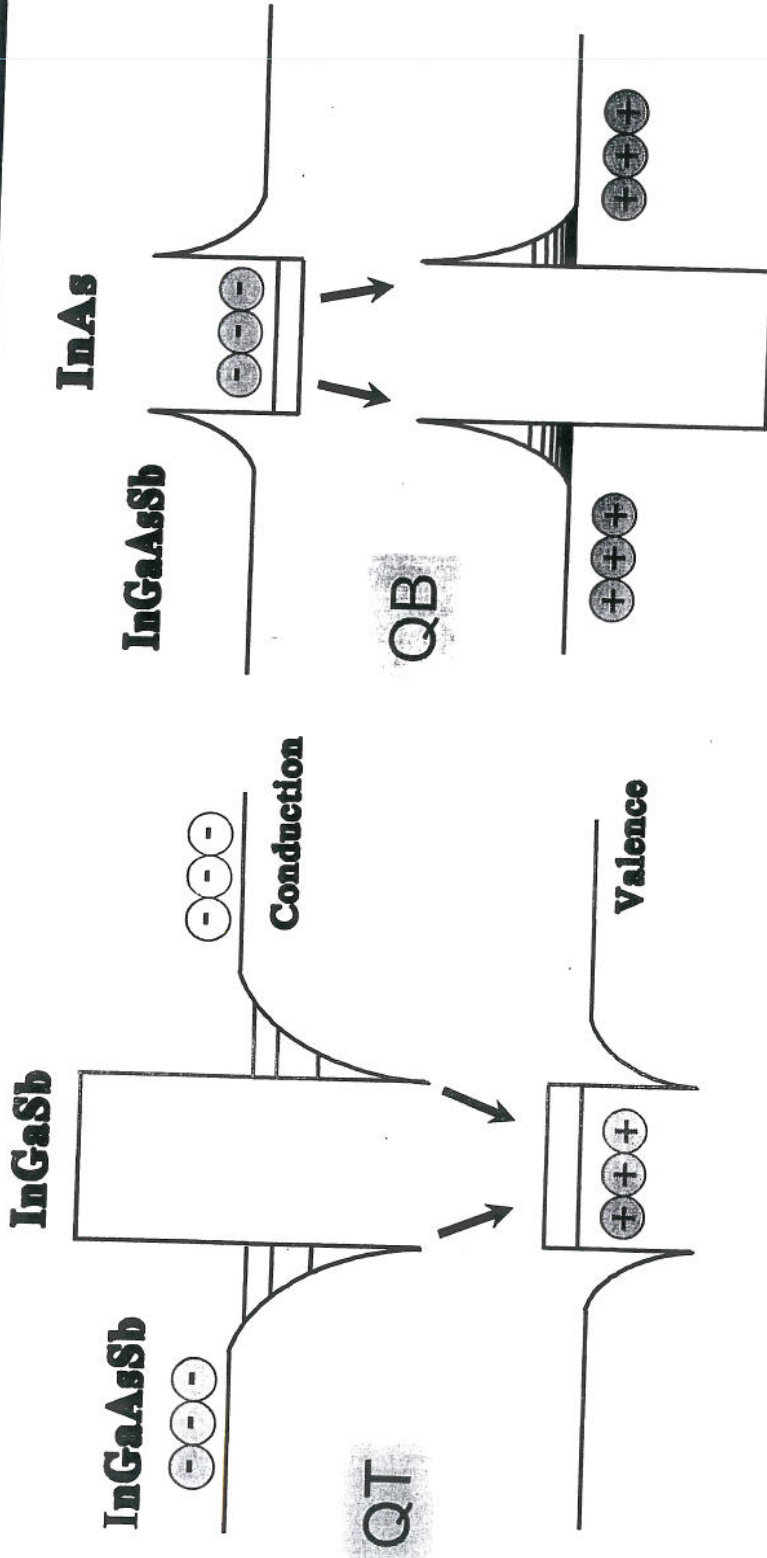
Yes. We see an especially low internal efficiency for the QB. This suggests that the holes are not effectively used once generated.

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➤ Comparison with 3.4  $\mu\text{m}$  W laser shows that the poor  $\eta_i$  of QB laser is not solely due to the larger quantum defect.

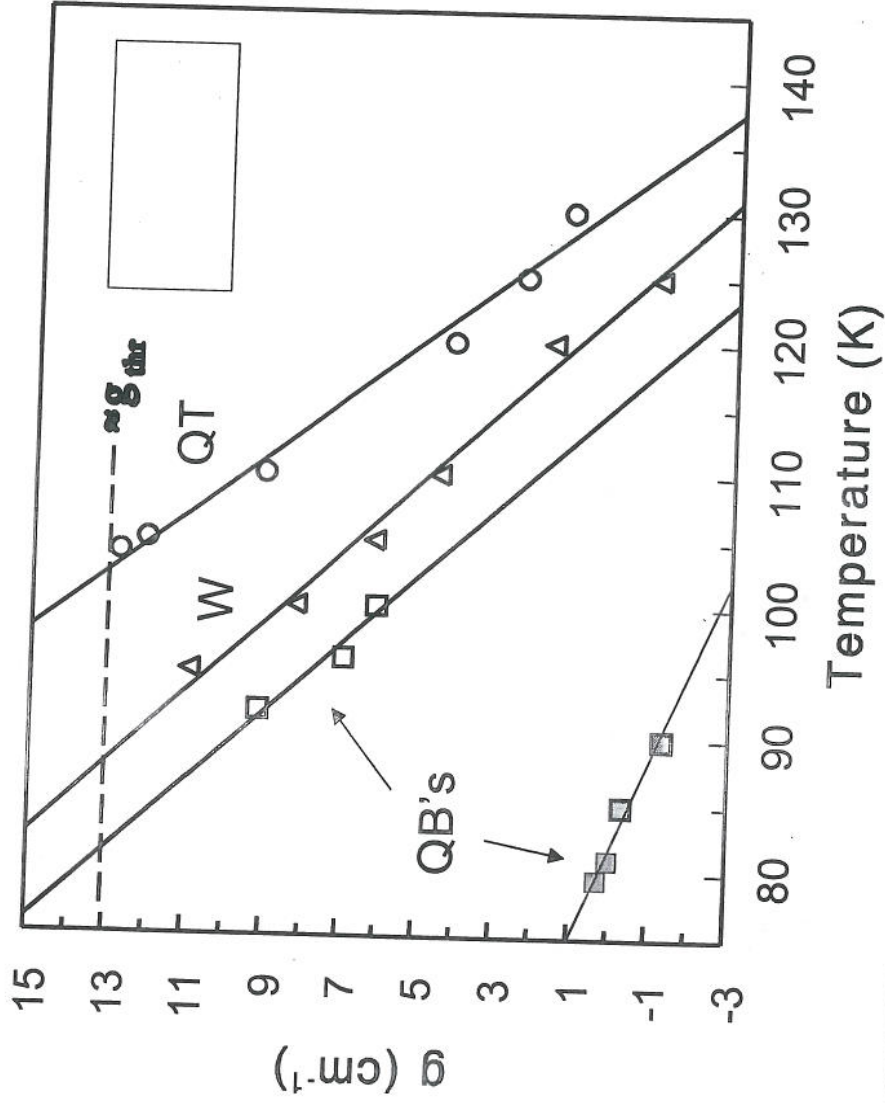
Why is the performance of the electron well laser so much worse than that of the hole well laser ?  
Band bending occurs in each structure.



■ The effective hole mass is much greater than the effective electron mass ( $m_h \gg m_e$ ) so the valence band states are much more densely packed near the band edge in the QB than are the conduction band states in the QT. Hence, in the QB, the gain is diluted over a much larger density of states.

# Peak gain as a function of temperature at constant pump power.

The peak gain in the QB is diluted over a much larger density of states.

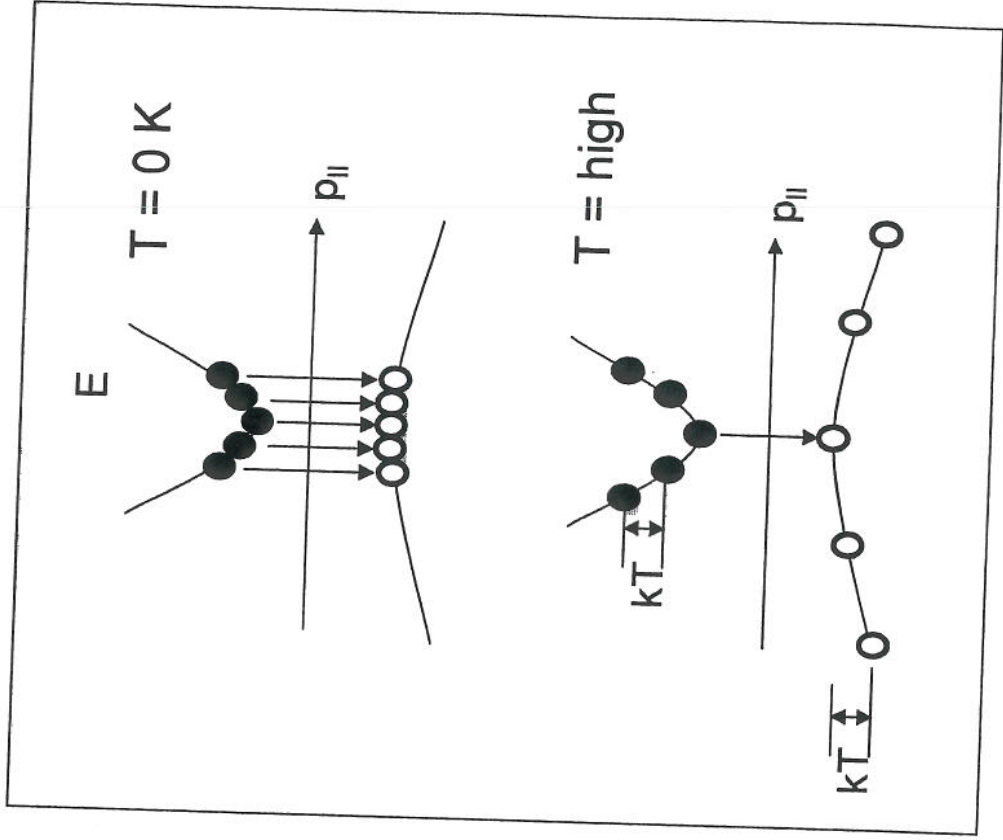
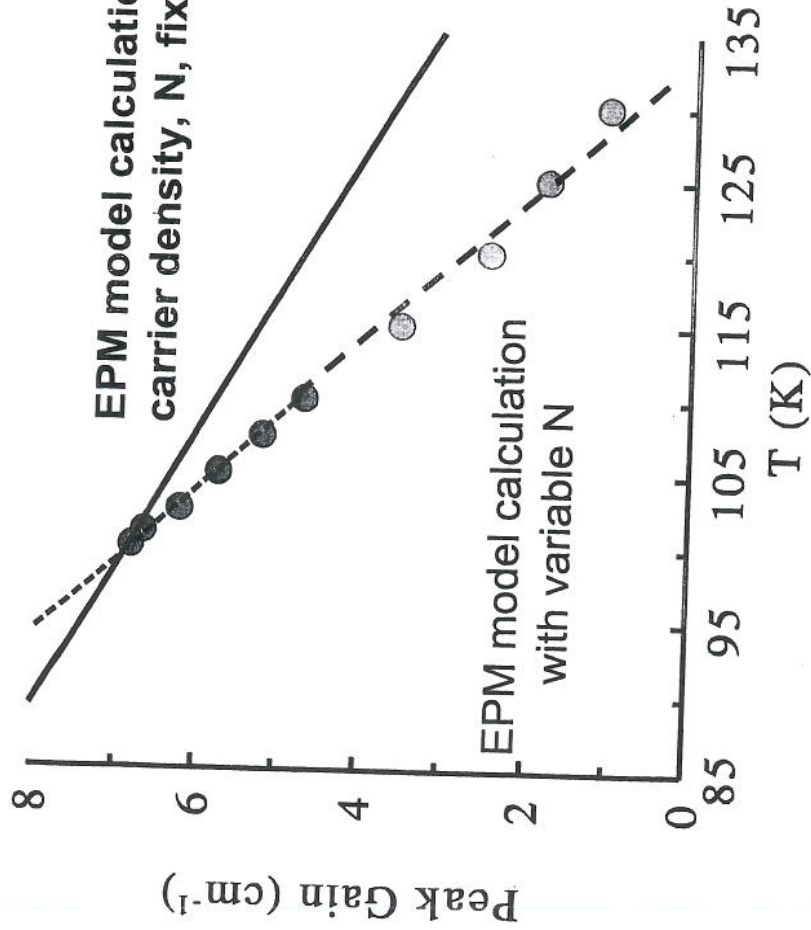


- 14 QW QB in a dilute waveguide; # QW's and waveguide equivalent to QT and W design
- 6 QW QB in a tight waveguide.

# Superlattice empirical pseudopotential model (SEPM) prediction of gain vs. T at constant pump power.

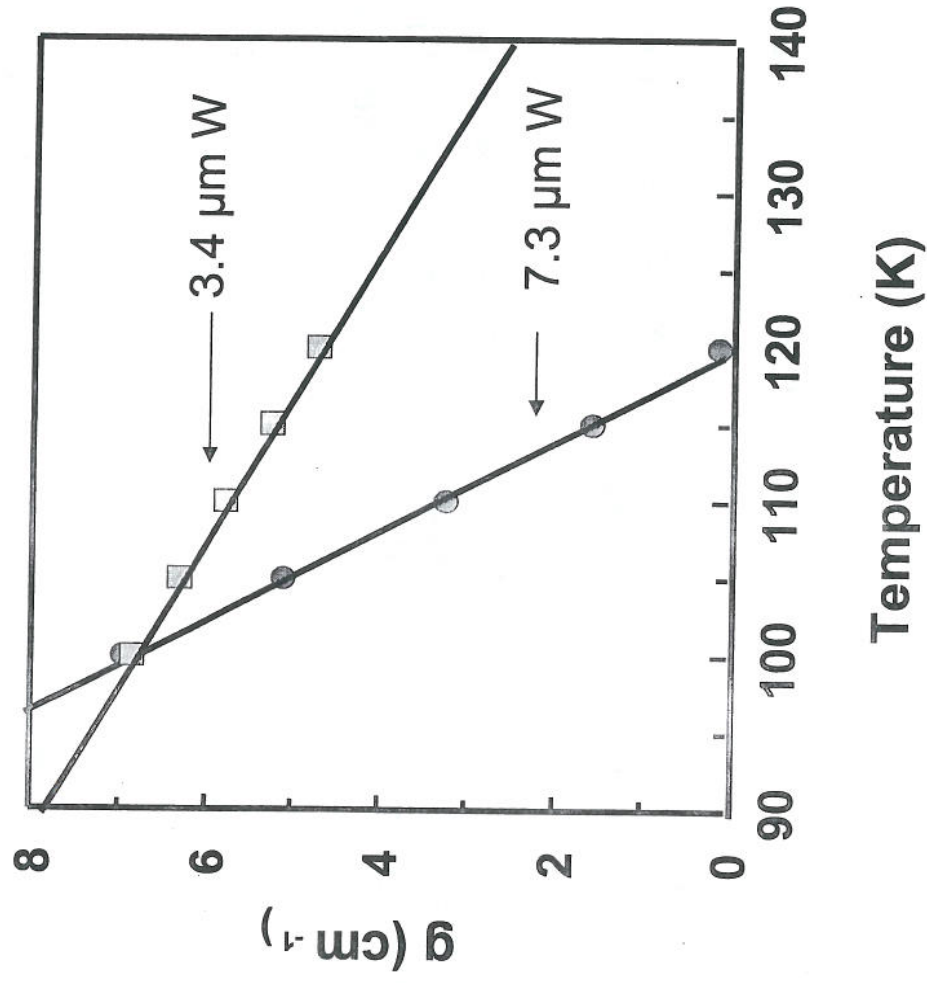
Momentum spread of holes accounts for much of the drop in gain in W-lasers.

- - Measurement on 3.4  $\mu\text{m}$  W laser at constant pump power,  $\sim 865$  mW.



# SEPM predicts larger gain fall-off at longer $\lambda$ operation.

Due to increased hole-dilution, more than one conduction band state being populated, and reduced hole transport.



# Conclusions

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Low waveguide losses were observed in W lasers, a hole well only laser (QT), and an electron well only laser (QB).

The decrease in quantum efficiency as temperature is increased is mainly due to a decrease in the lasers internal efficiency,  $\eta$ . This is partially due to the increased momentum spread of the holes at higher temperatures.

The poor  $\eta$  and low  $T_1$  of the QB is due to the gain dilution incurred by the large density of valence-band states.

An effective hole quantum well is essential in producing a larger  $\eta$ . Without hole quantization or where the hole density of states is bulk-like, the performance is significantly degraded.