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Center for Optical Technologies

Quasi-Supercontinuum Interband Lasing Characteristics of Quantum Dot Nanostructures

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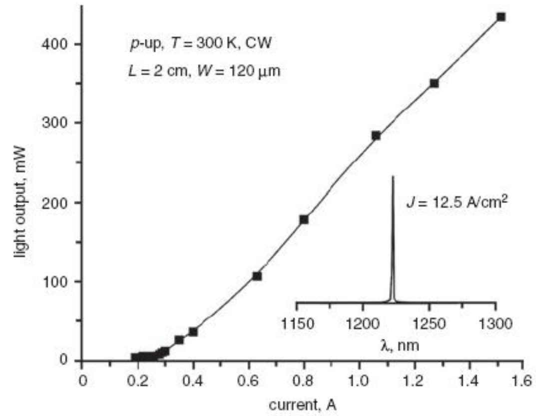
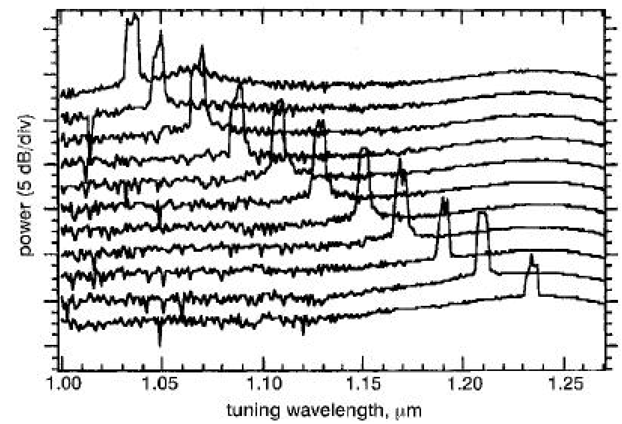
Quantum Dot Lasers

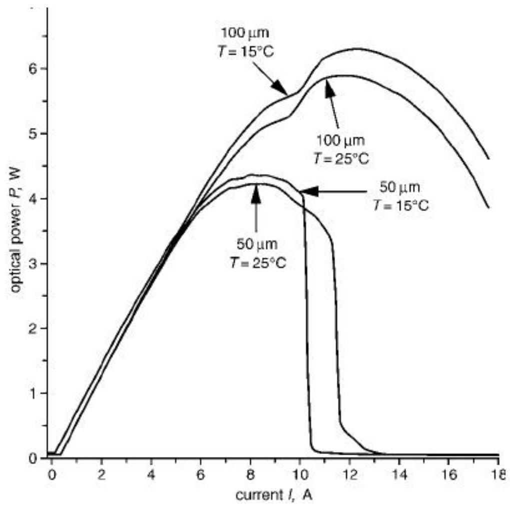
- **Low threshold current density[1] (11.7 A/cm²)**



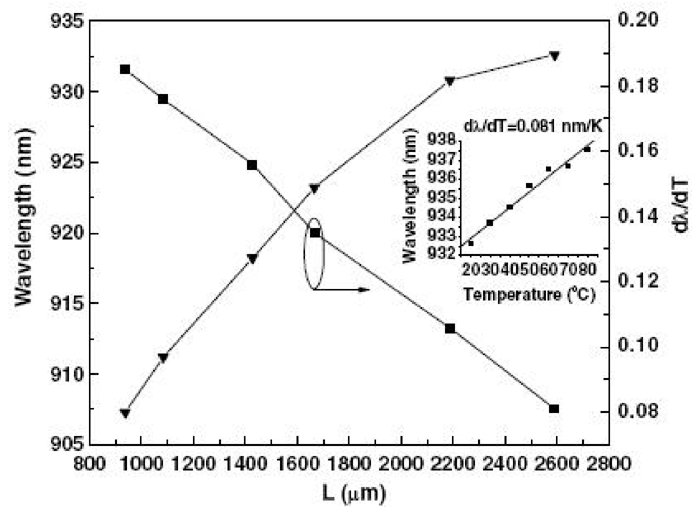
- **Broad gain spectrum[2] (201 nm)**



- **High power applications[3] (6.3 W CW at 15°C)**

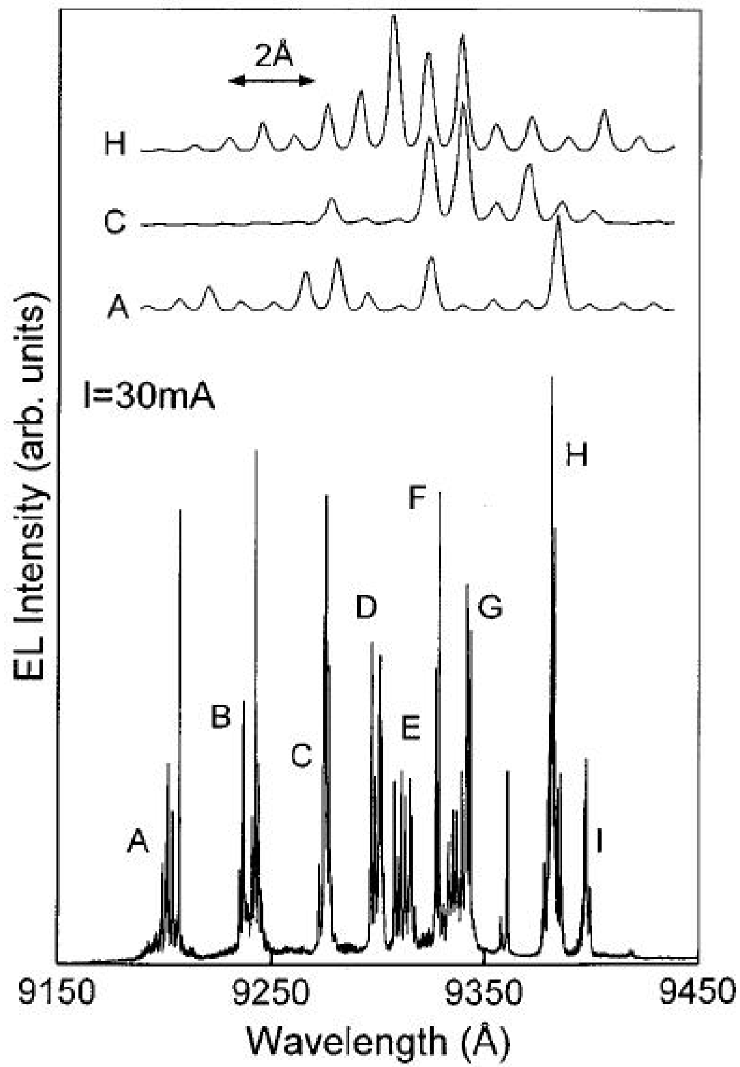


- **Enhanced temperature stability[4] (0.081 nm/K)**

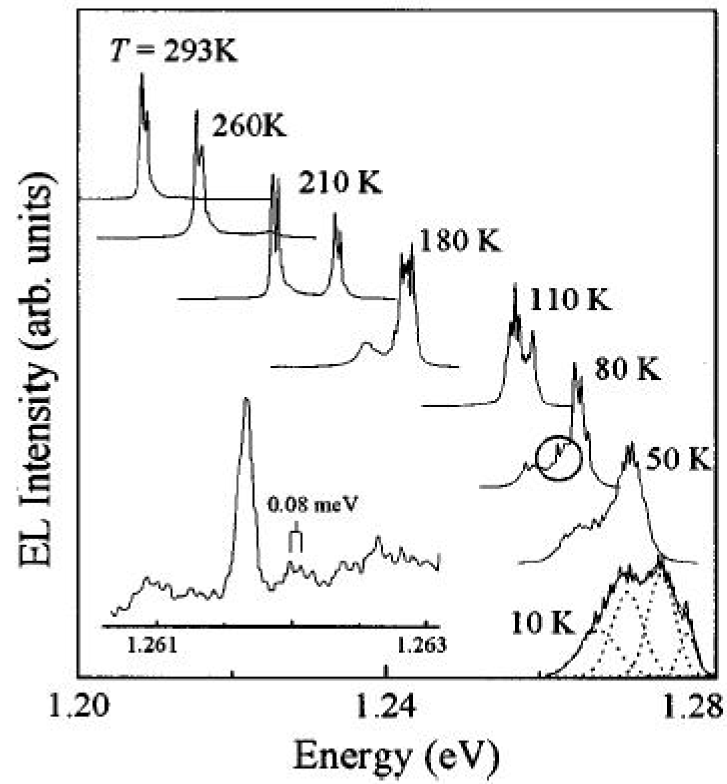


1. S. Freisem, et al., Electron. Lett. **44** (11), pp. 670-671, 2008.
2. Varangis, P. M., et al. Electron. Lett. **36** (18), pp. 1544-1545, 2008.
3. Sumpf, B., et al., Electron. Lett. **39** (23), pp. 1655-1657, 2003.
4. E-M Pavelescu, et al., Semicond. Sci. Technol. **23** (085022), 2008.

Unique Lasing Mechanism



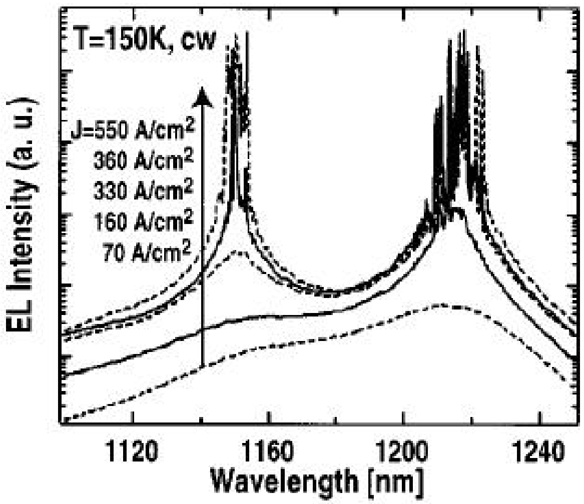
Multi-groups of lasing modes[1]

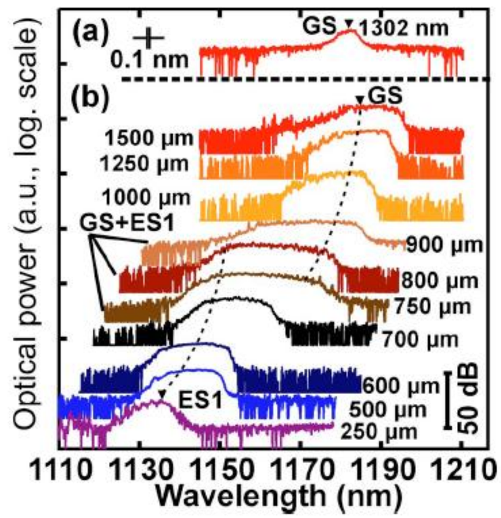


Thermal effect[2]

1. L. Harris, et al., Appl. Phys. Lett. **73** (7), pp. 969-971, 1998.
2. A. Patane, et al., J. Appl. Phys. **85** (1), pp. 625-627, 1999.

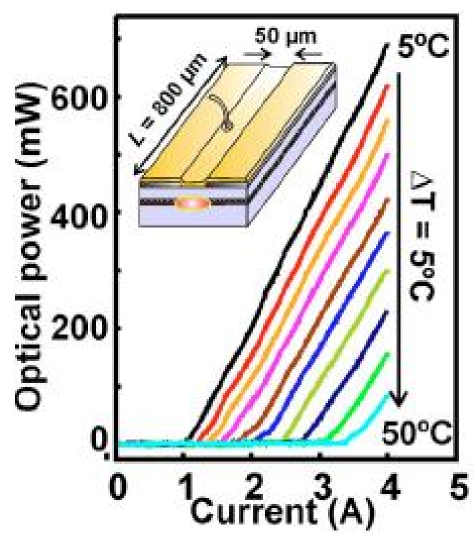
Quasi-Supercontinuum Lasing

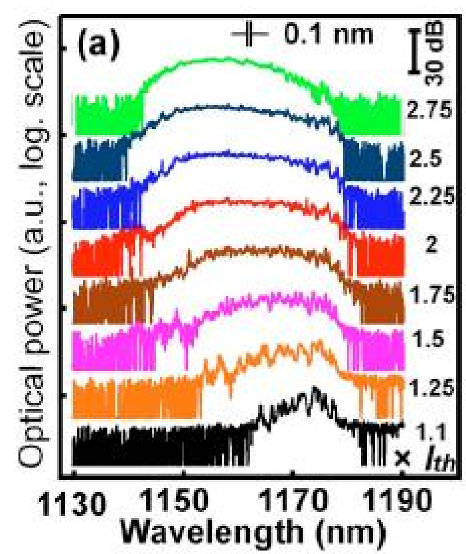




Two-state lasing[1]

Quasi-Supercontinuum lasing[2]



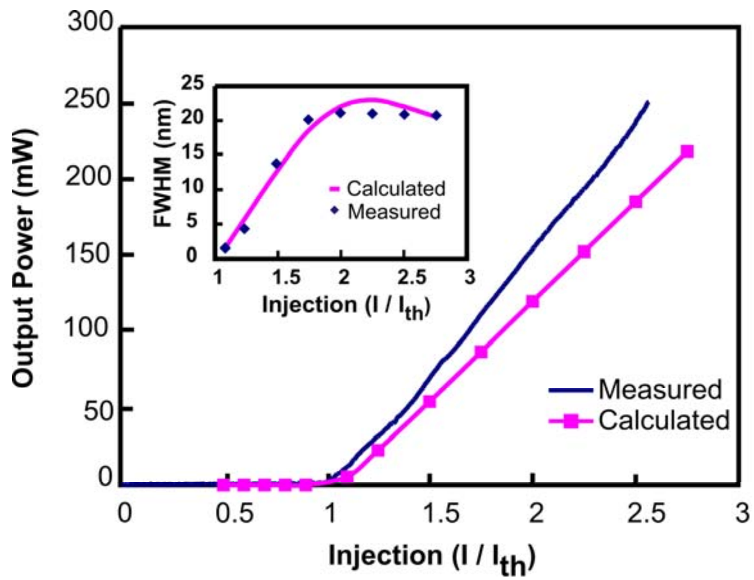


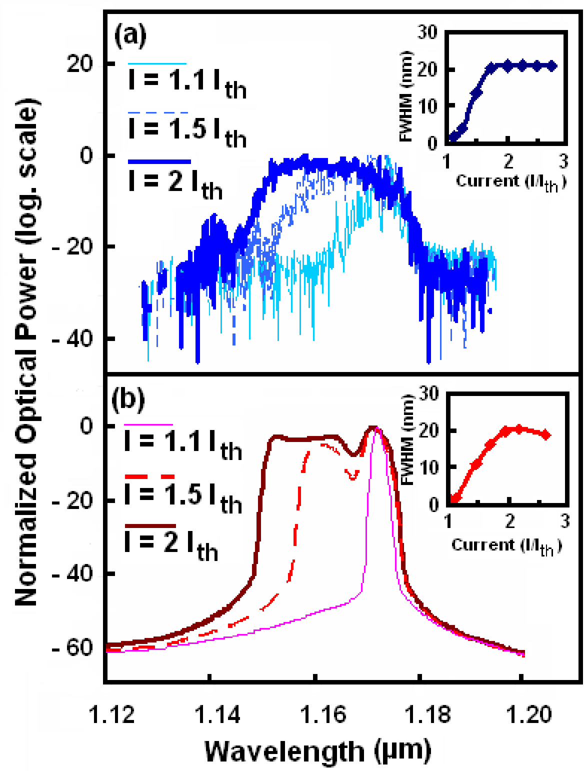
1. A. Markus, et al., Appl. Phys. Lett. **82** (12), pp. 1818-1820, 2003.
2. H. S. Djie, et al., Opt. Lett. **32** (1), pp. 44-46, 2007.

Applications of Broad Gain Materials and Broadband Lasers

- **Optical Telecommunications**
- **Spectroscopy & Sensing**
- **Metrology**
- **Imaging**
- **Others**

Theoretical Model

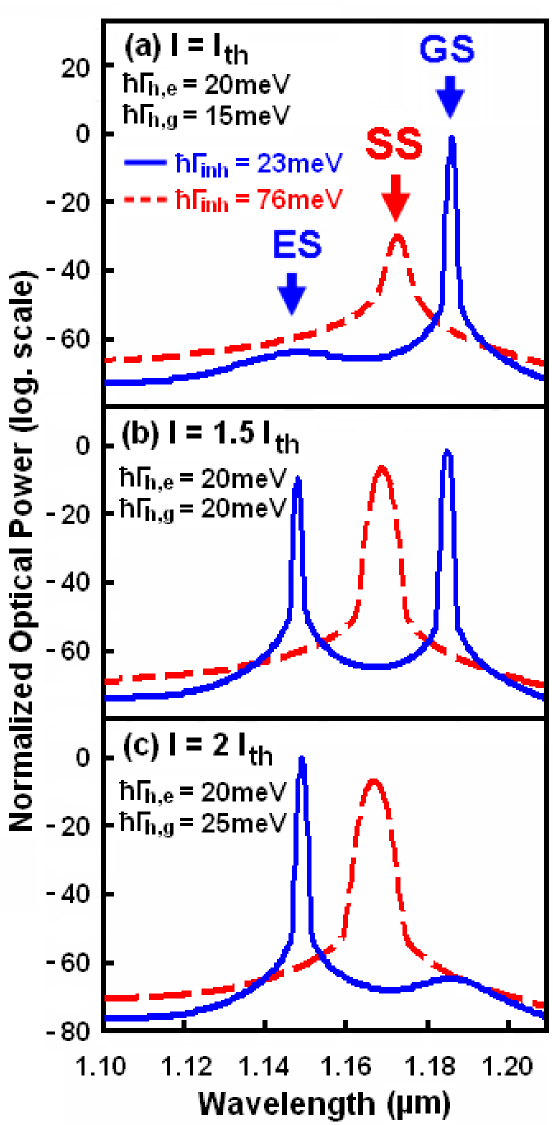


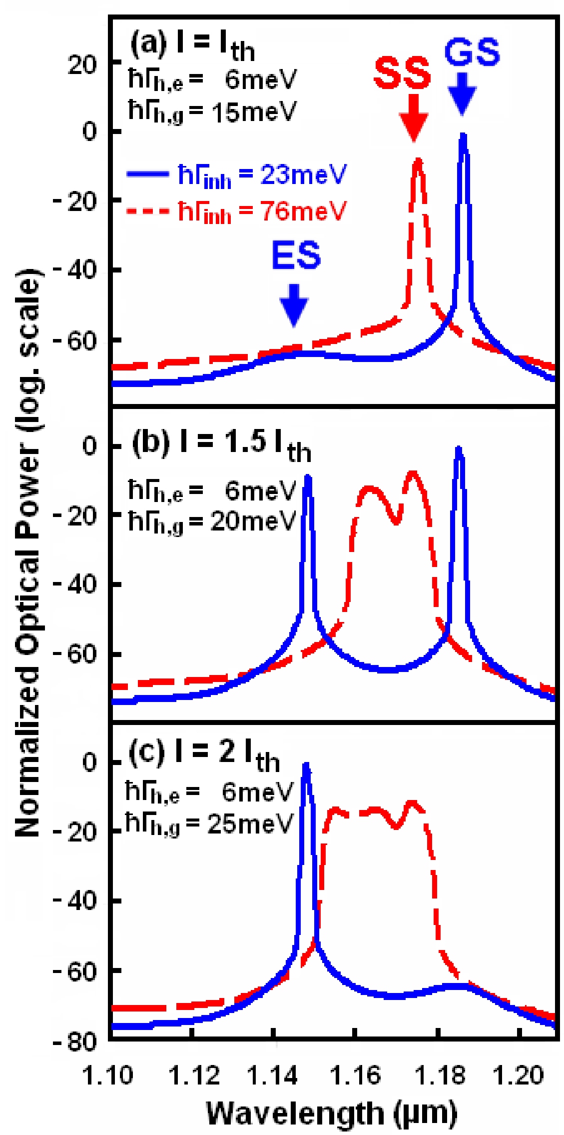


- The calculated output power shows slight variation with experimental measurement that may due to the cleaving precision of the device.
- The calculated linewidth match well with measured data due to the optical gain broadening.

H. S. Djie *et al.*, Opt. Lett. 32, 44 (2007).
C. L. Tan *et al.*, Appl. Phys. Lett., 91, 061117 (2007).
C. L. Tan *et al.*, Comp. Mater. Sci., in press (2008).

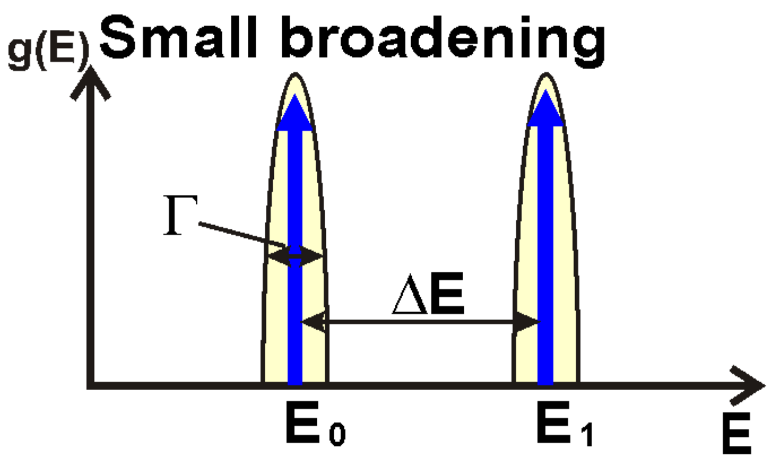
Theoretical Model



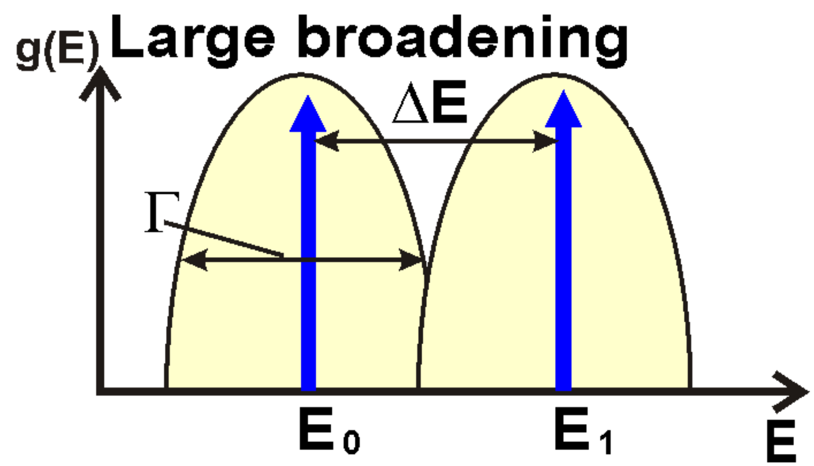


C. L. Tan *et al.*, Appl. Phys. Lett., 91, 061117 (2007).

Importance



$\Gamma \leqslant \Delta E$

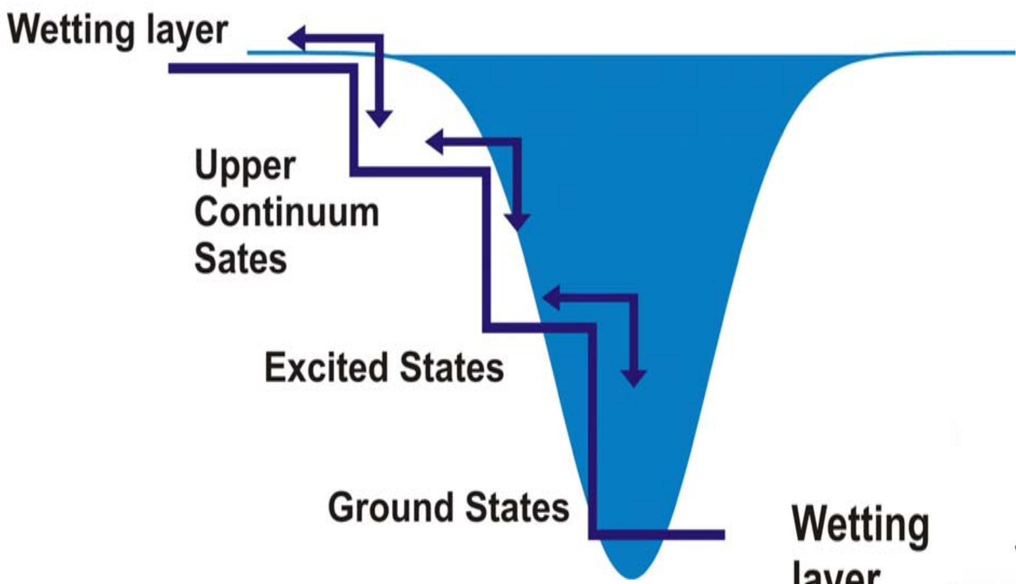


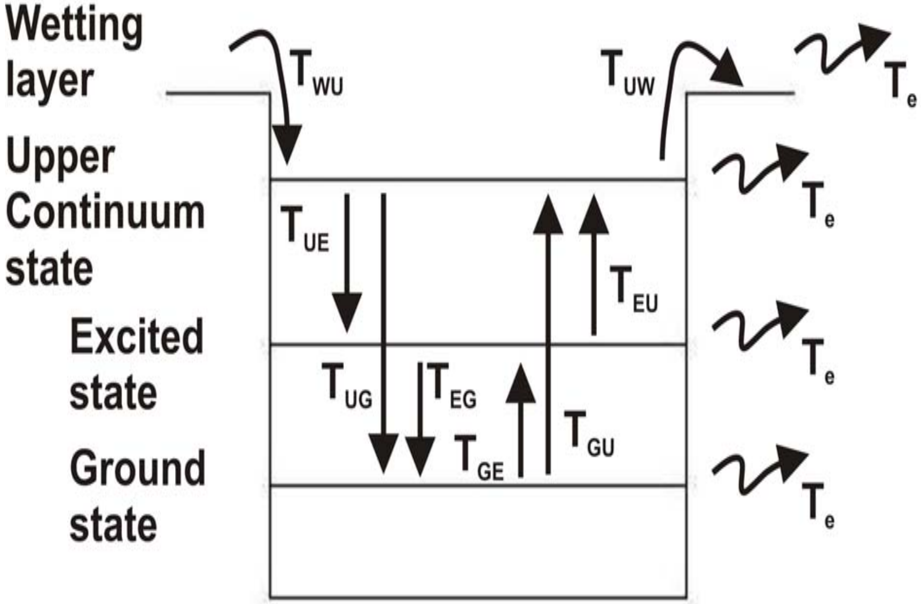
$\Gamma \geqslant \Delta E$

- **Conditions to reach critical occurrence of ultrabroad interband lasing**
- **Minimum ambiguity and efforts of QD growth conditions**
- **Engineering of ΔE via post-growth intermixing technique.[1]**

1. C. L. Tan *et al.*, Appl. Phys. Lett., in press, (2008).

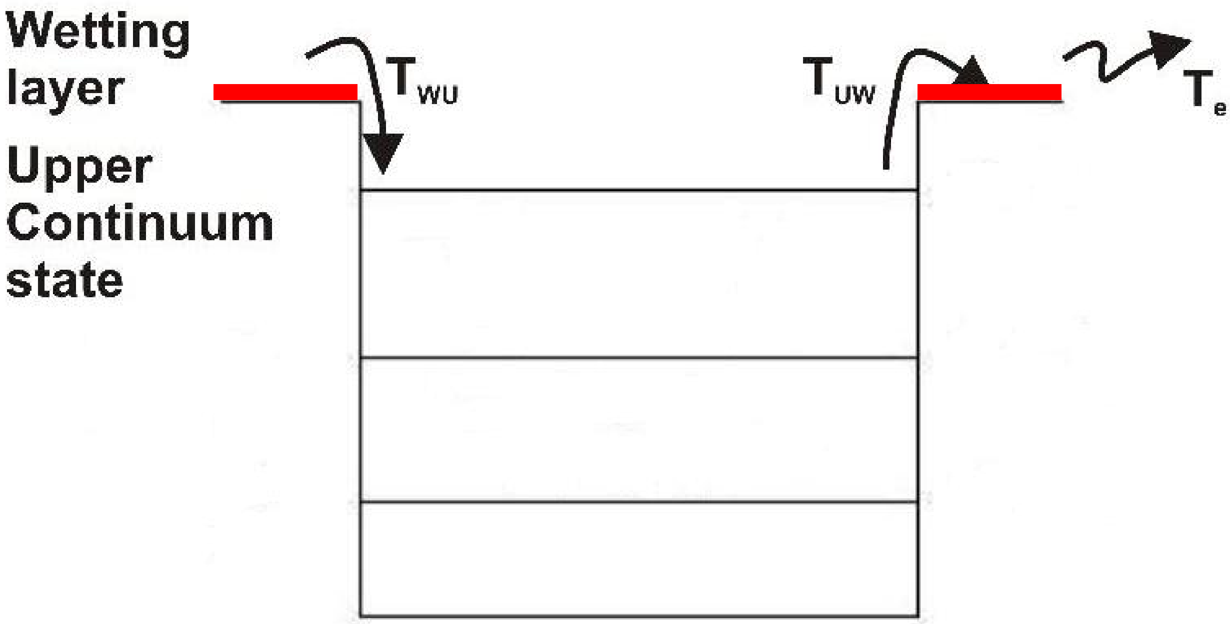
Theoretical Model





C. L. Tan *et al.*, Appl. Phys. Lett., 91, 061117 (2007).
C. L. Tan *et al.*, Comp. Mater. Sci., in press (2008).

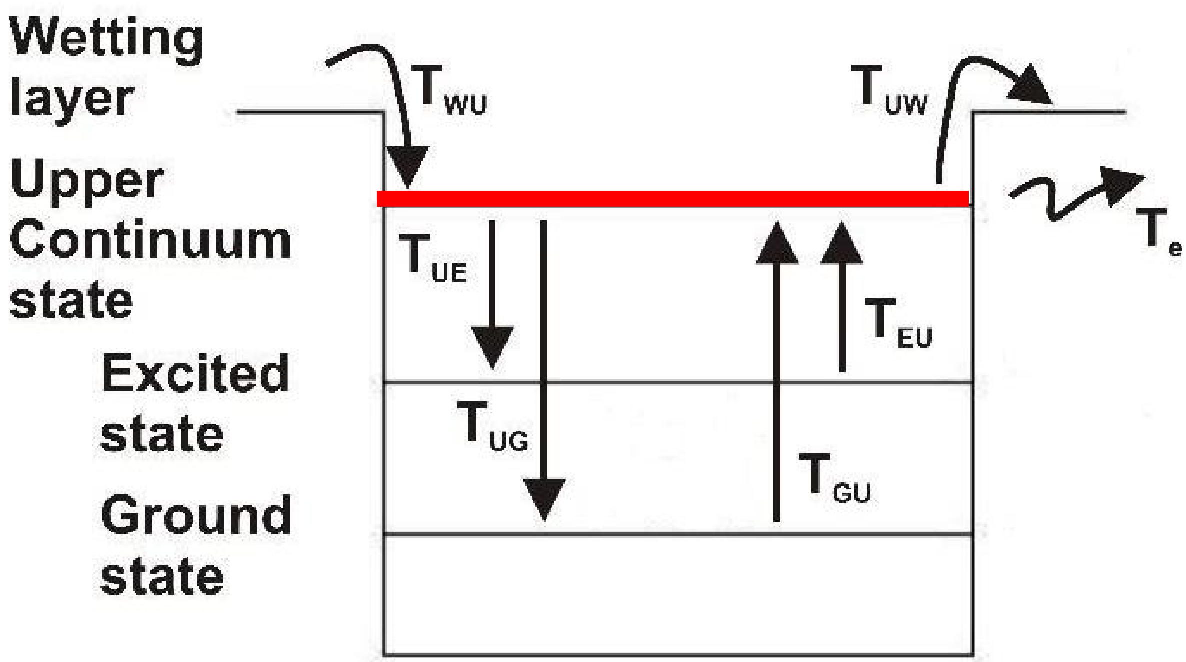
Theoretical Model



$$\frac{dN_w}{dt} = \frac{\eta_i I}{q} - \frac{N_w}{T_{wr}} - \frac{N_w}{T_{wu}} - \frac{N_e}{T_e} + \frac{\sum N_{u,j}}{T_{uw}}$$

C. L. Tan *et al.*, Appl. Phys. Lett., 91, 061117 (2007).
C. L. Tan *et al.*, Comp. Mater. Sci., in press (2008).

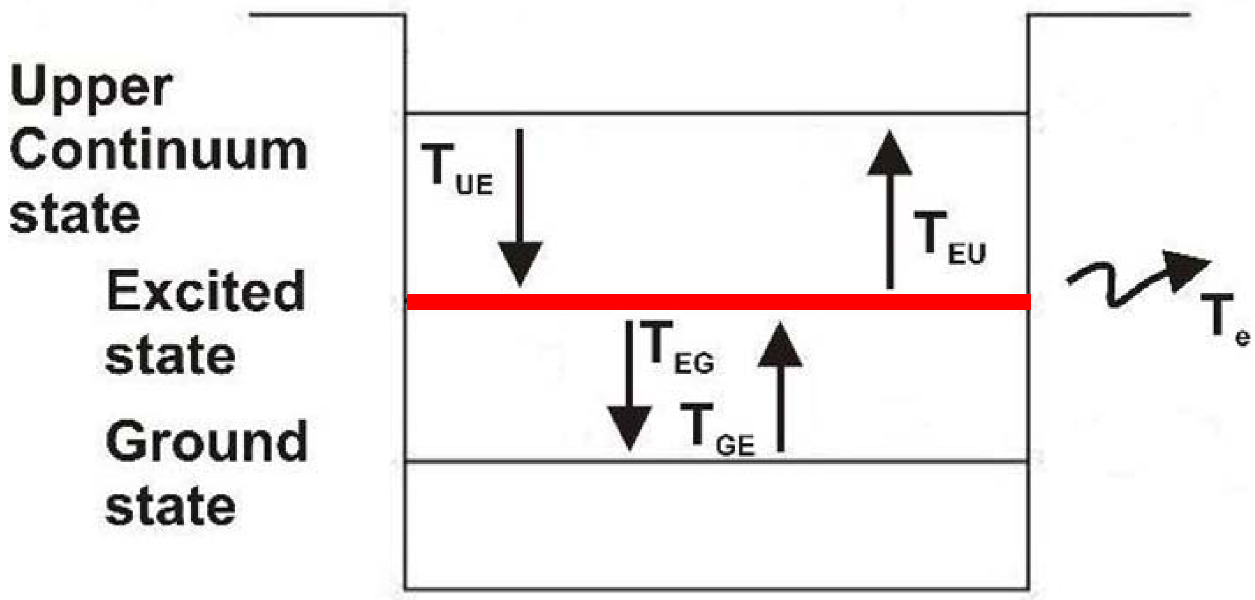
Theoretical Model



$$\frac{dN_{u,j}}{dt} = \frac{N_w G_n}{T_{wu,j}} + \frac{N_{g,j}}{T_{gu,j}} + \frac{N_{e,j}}{T_{eu,j}} - \frac{N_{u,j}}{T_{ug,j}} - \frac{N_{u,j}}{T_{ue.j}} - \frac{N_{u,j}}{T_{uw}} - \frac{N_{u,j}}{T_r} - \frac{N_{u,j}}{T_e} - \frac{c\Gamma}{n_r}\sum_m g_{mn} S_m$$

C. L. Tan *et al.*, Appl. Phys. Lett., 91, 061117 (2007).
C. L. Tan *et al.*, Comp. Mater. Sci., in press (2008).

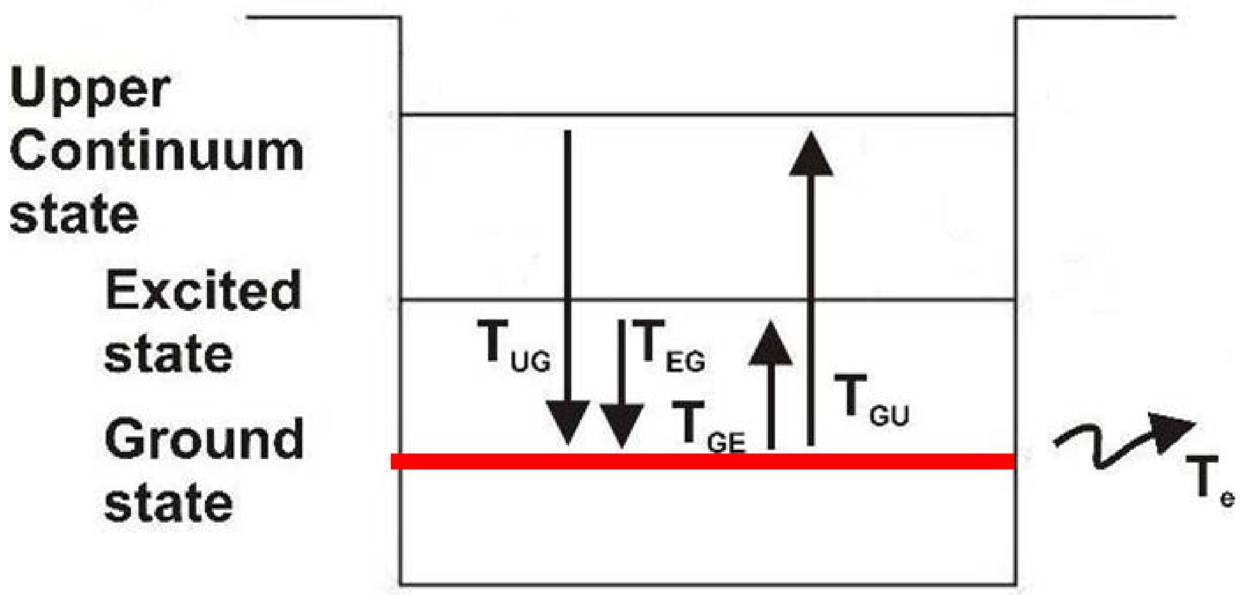
Theoretical Model



$$\frac{dN_{e,j}}{dt} = \frac{N_{u,j}}{T_{ue,j}} + \frac{N_{g,j}}{T_{ge,j}} - \frac{N_{e,j}}{T_{eu,j}} - \frac{N_{e,j}}{T_{eg.j}} - \frac{N_{e,j}}{T_r} - \frac{N_{e,j}}{T_e} - \frac{c\Gamma}{n_r}\sum_m g_{mn} S_m$$

C. L. Tan *et al.*, Appl. Phys. Lett., 91, 061117 (2007).
C. L. Tan *et al.*, Comp. Mater. Sci., in press (2008).

Theoretical Model



$$\frac{dN_{g,j}}{dt} = \frac{N_{u,j}}{T_{ug,j}} + \frac{N_{e,j}}{T_{eg,j}} - \frac{N_{g,j}}{T_{gu,j}} - \frac{N_{g,j}}{T_{ge.j}} - \frac{N_{g,j}}{T_r} - \frac{N_{g,j}}{T_e} - \frac{c\Gamma}{n_r}\sum_m g_{mn} S_m$$

C. L. Tan *et al.*, Appl. Phys. Lett., 91, 061117 (2007).
C. L. Tan *et al.*, Comp. Mater. Sci., in press (2008).

Theoretical Model

Optical gain modal:

$$g_{mn,l} = \frac{2\pi q^2 \hbar D_l N_D}{c n_r \varepsilon_0 m_0^2} \frac{|P_{cv}^{\sigma}|^2}{E_{cv,l}} (2P_{n,l} - 1)\ldots$$

$$G_{n,l} B_{cv,l}(E_m - E_{n,l})$$

Homogeneous Broadening function:

$$B_{cv,l}(E_m - E_{n,l}) = \frac{\hbar \Gamma_{cv,l} / \pi}{(E_m - E_{n,l})^2 + (\hbar \Gamma_{cv,l})^2}$$

M. Sugawara *et al.*, Phys. Rev. B, 61, 11 (2000).

M. Sugawara *et al.*, J. Appl. Phys., 97, 043523 (2005).

Theoretical Model

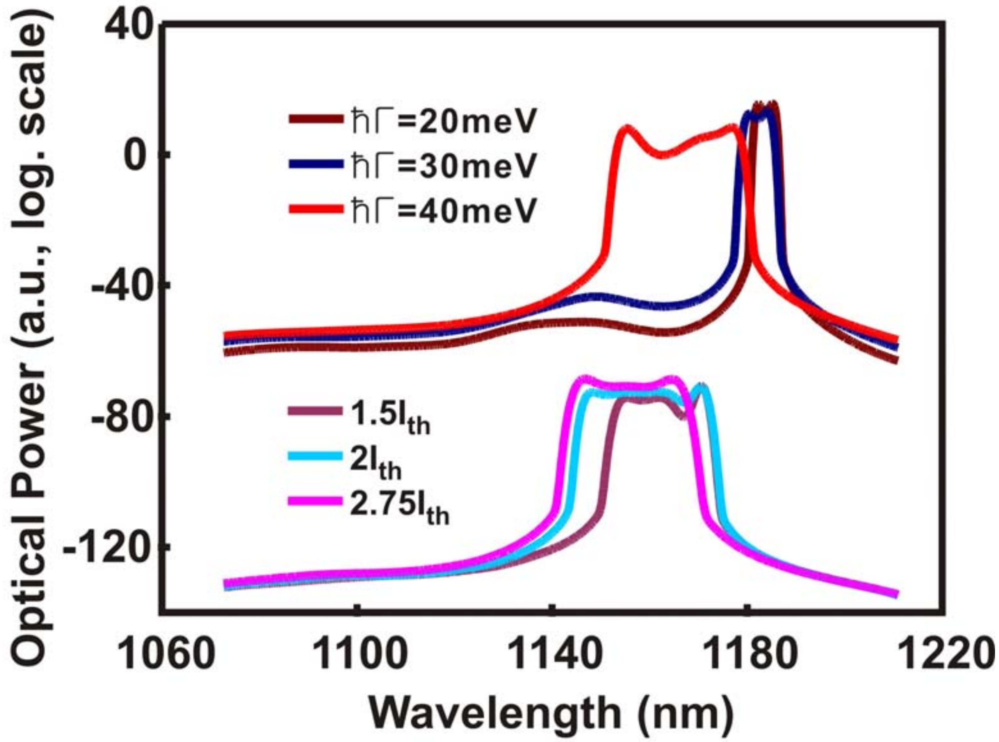
where,

$$G_{n,l}(E_m - E_{n,l}) = \frac{1}{\sqrt{2\pi}\,\xi_o}\exp[-(E_m - E_{n,l})^2/(2\xi_o^2)]$$

$$E_{n,l} = E_{cv,l} - (M - n)\Delta E$$

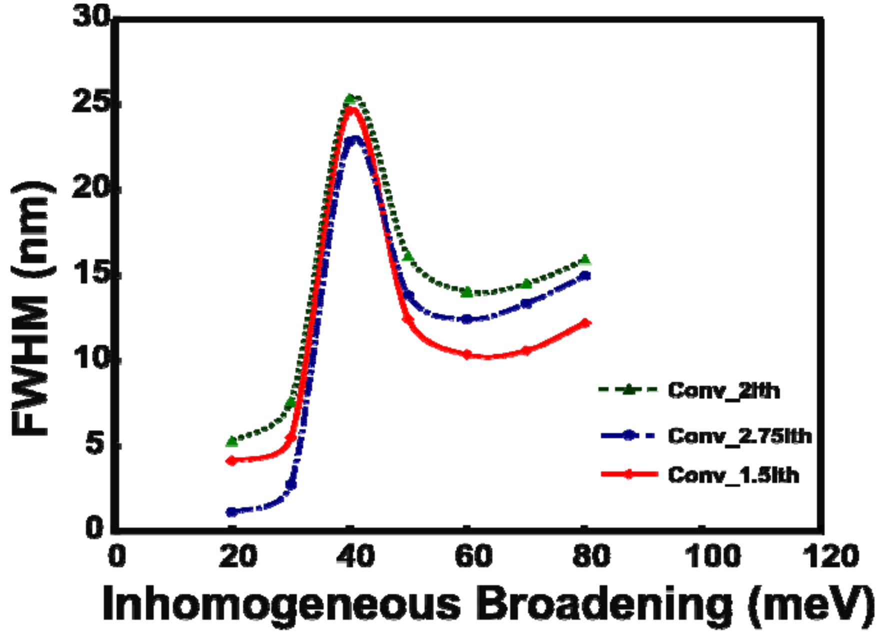
$$P_{n,l} = \frac{N_{n,l}}{2D_l N_D V_A G_n}$$

Results

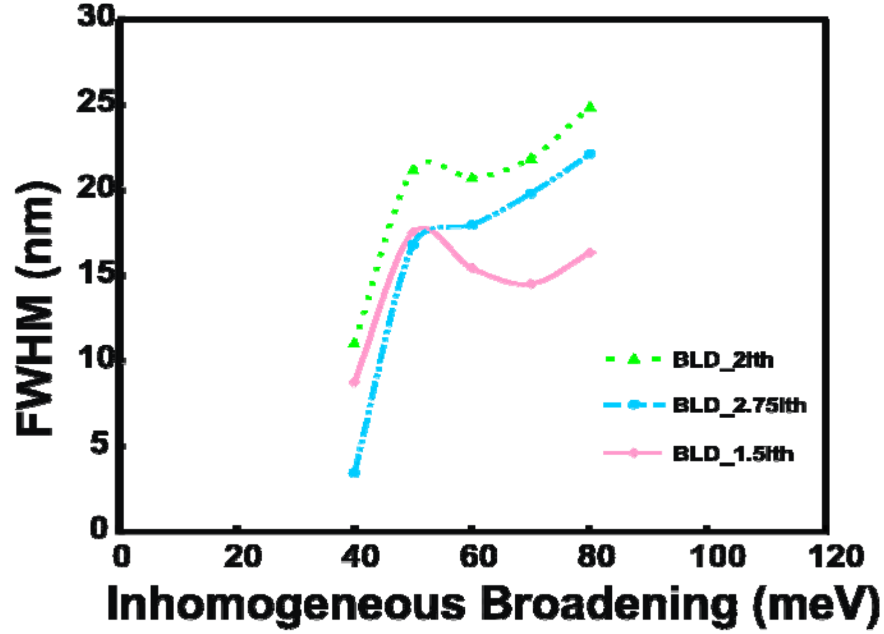


- The lasing spectra for different quantum dot inhomogeneity in typical simulation model at $I=1.5 \times I_{th}$.
- The lasing spectra of quantum-dot (inhomogeneous broadening FWHM ~ 80 meV) in the proposed simulation model.

Results



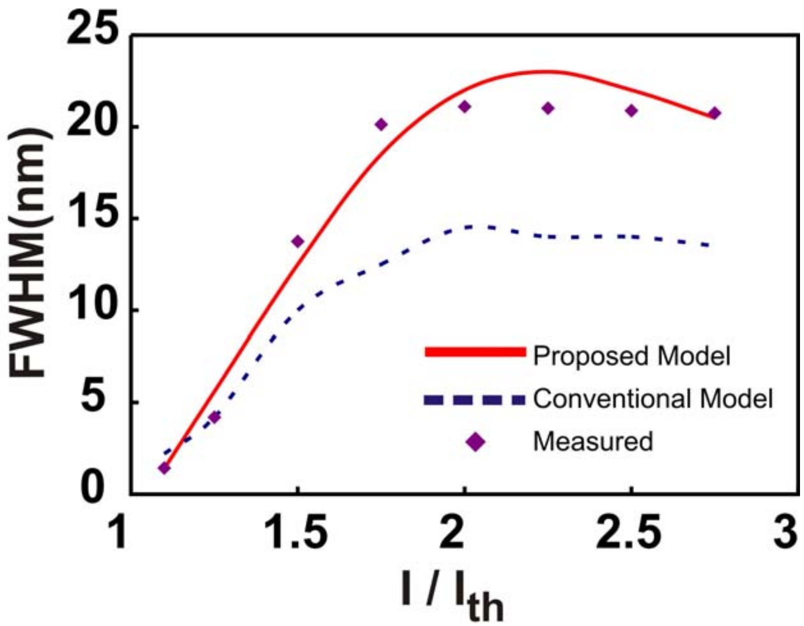
Typical Model

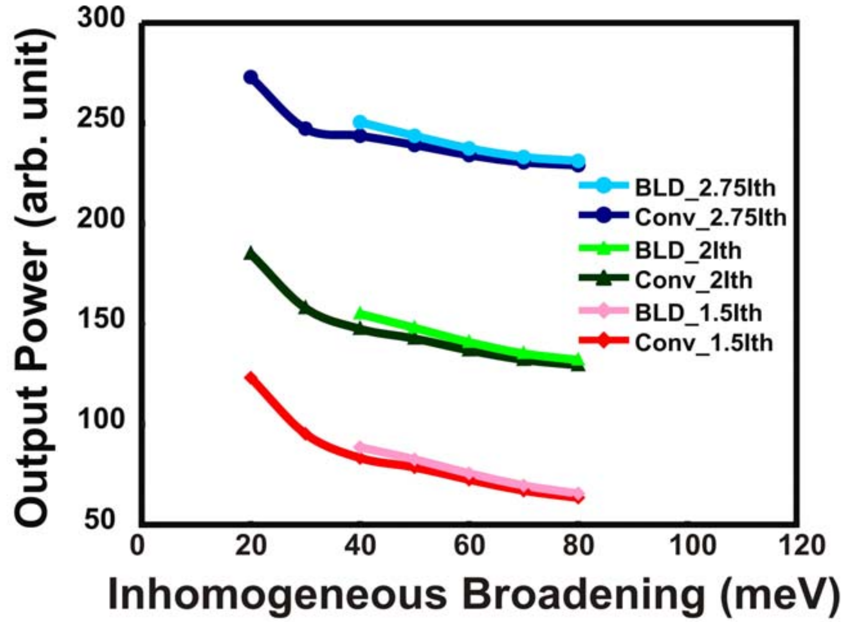


Broadband Model

- The changes of lasing linewidth with inhomogeneous broadening of the quantum dot system as the injection increases in both broadband and typical simulation model.

Results





- The changes of linewidth with injections in both calculated and measured experimental results.
- The changes of total output power with inhomogeneous broadening of the quantum dot system at different current injections for both broadband and typical quantum dot lasers.

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Conclusions

- There is a tolerance between ΔE, QD inhomogeneity and output power in order to obtain an intended broad lasing bandwidth.
- The fundamental guideline to achieve broad linewidth with desired output power is to ensure comparable or smaller values of ΔE as compared to QD inhomogeneity to compromise the drawbacks of large QD inhomogeneity.
- Carrier mechanism is predicted to change once ΔE is comparable to QD inhomogeneity.

Thank You

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Simulation parameters

E_{GS} = 1050meV	$T_{0,wu}$ = 1ps
E_{ES} = 1090meV	$T_{0,ue} = T_{0,eg} = T_{0,ug}$ = 3.4ps
D_G = 1	n_r = 3.5
D_E = 3	T_r = 1ns
D_U = 10	$N_D = 1.67*10^{23}$
L_{ca} = 800 μ m	$V_A = 9.6*10^{-16}$
$R_1 = R_2 = 0.3$	ß = 10^{-4}
$\alpha_i = 4.5cm^{-1}$	Γ_{QD} = 0.03
T_{wr} = 0.4ns	Γ_{WL} = 0.01
T_e = 0.38ns	Γ_{inhomo} = 23meV, 76meV
$T_{0,uw}$ = 10ps	ΔE = 0.22meV