Nano Writing Technology

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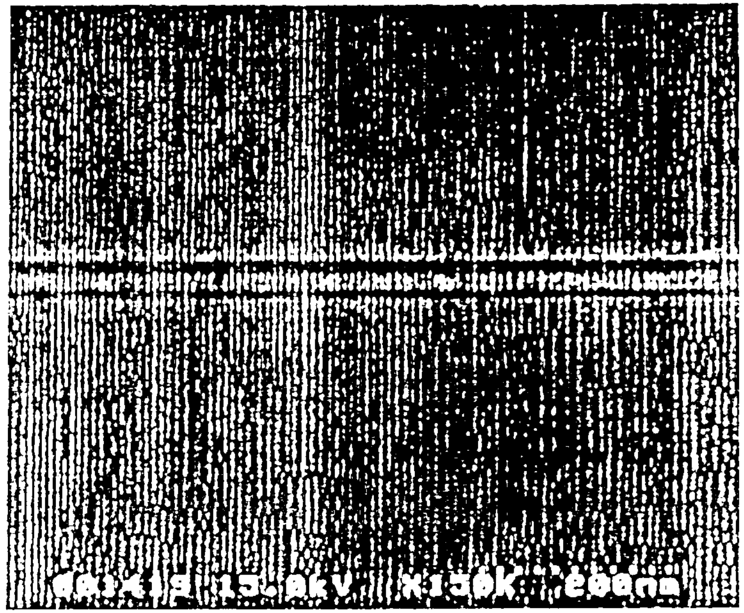
Quantized state in ultra-thin film

Electron confined
in 5-20 nm thick semiconductor film
↓
Standing wave
↓
Quantized state



Cross sectional view of
10 nm & 5 nm thick
GaInAsP/InP quantum well layer
grown by OMVPE

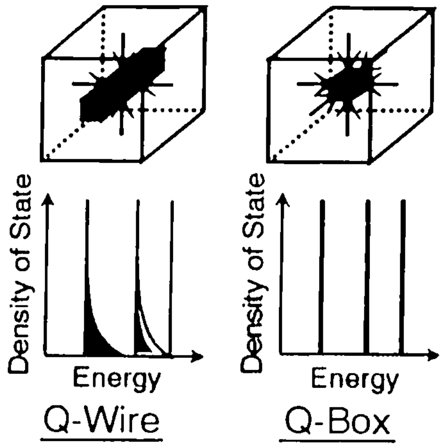
Optical devices

Quantum well laser with strained layer

Electron devices

High Electron Mobility Transistors (HEMTs) with modulation doping

Quantum-Wire (Box) Lasers



Quantization of energy levels in conduction band.

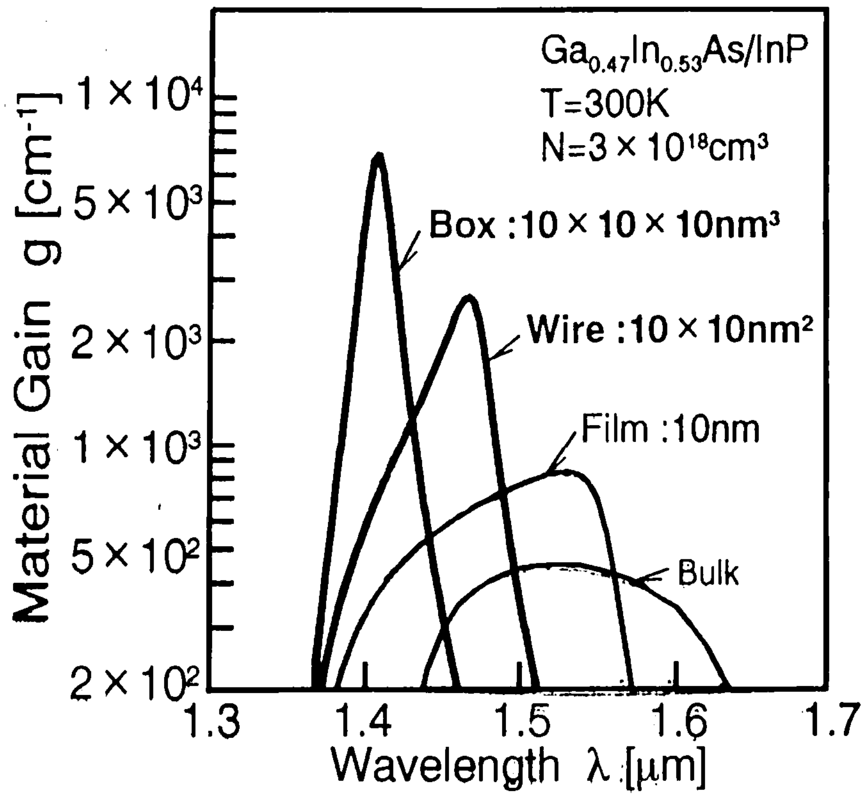
↓

High optical gain

↓

For Lasers

Low threshold current
High differential efficiency
Narrow linewidth property

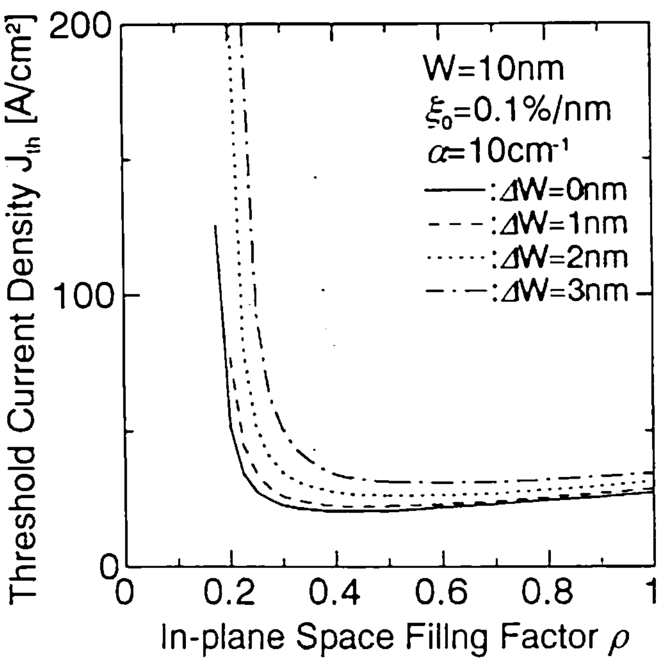


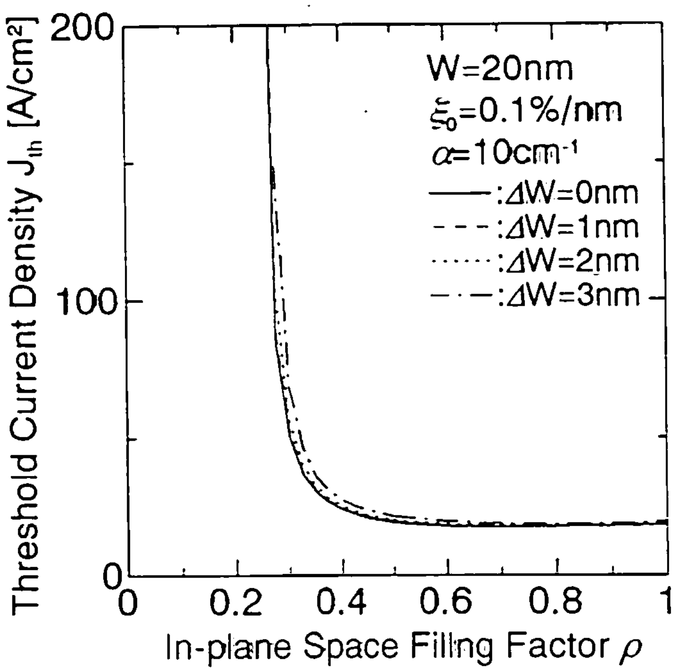
(M. Asada et al. JQE 22 (1986) 1915.)

Required density of Quantum wire laser

To overcome optical loss in cavity,

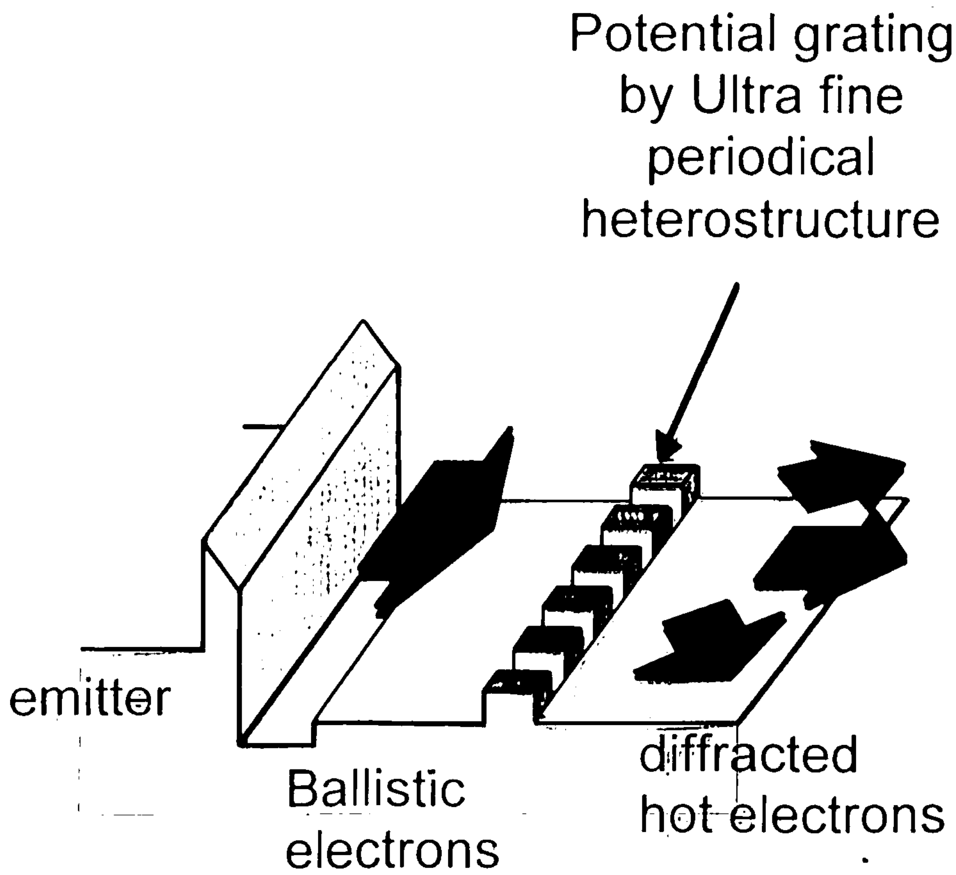
High density of quatum wire
is required.





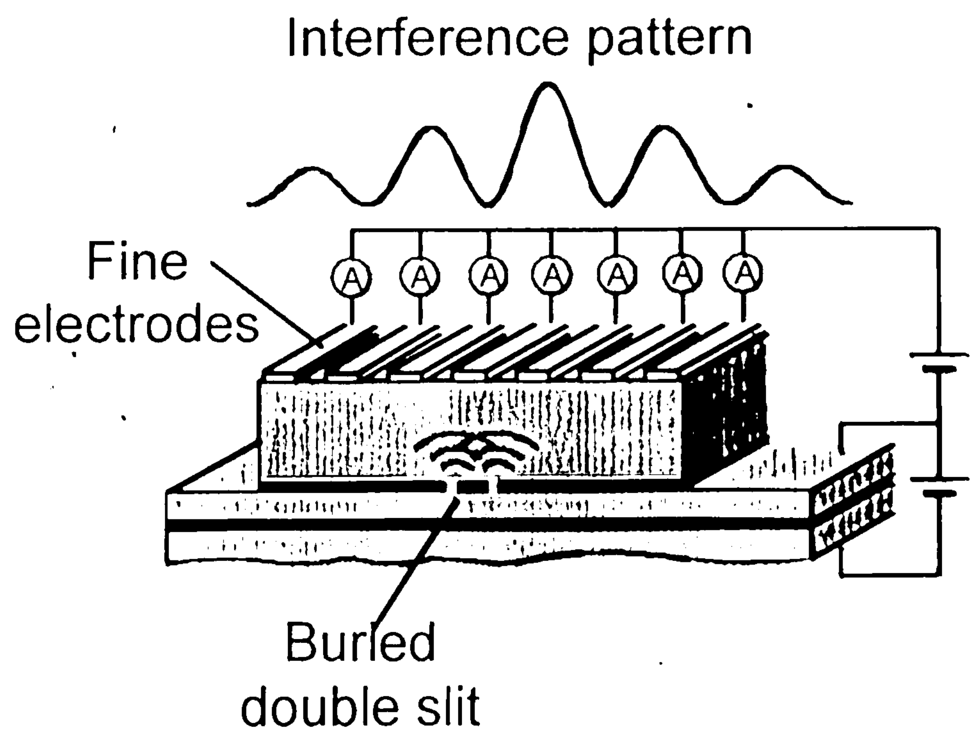
Lateral nano size for Electron devices

Ballistics electron (Long coherent length)
Lateral size (10-20 nm) =An electron Wavelength



Ultrahigh speed
Transistors /A-D converter?

Young's double slit experiment in semiconductors



Contents of this talk

Requirements of EBL machine

50 nm pitch quantum wire laser
(resist:ZEP-520 with 10 % C-60)

Toward electron wave devices,

25 nm pitch InP pattern buried in a GaInAs structure
(resist:calixarene)
80 nm pitch Au/Cr electrodes
(resist: PMMA / ZEP-520 with 10% C-60)

E-BEAM LITHOGRAPHY

JEOL JBX-5FE & JBX-6000 FS

Beam spot	5nm (for small size)
Accelerating voltage	50 kV (to reduce forward & back scattering)
Beam current	100 pA (to reduce exposure time by ZrO/W schottky emitter)
Accuracy of stage motion	0.62 nm (to reduce deformation of pattern)

High Resolution Resist

Positive resist

Exposed area → Scission of chain

→ Lower Molecular Weight

→ Soluble

(No exposed area:Insoluble)

Negative resist

Exposed area → Cross linking

→ Higher Molecular Weight

→ Insoluble

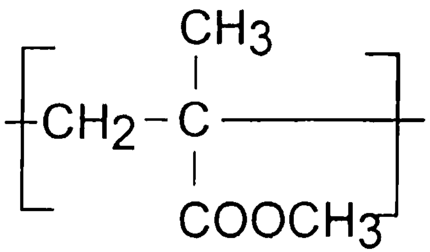
(Exposed area: soluble)

If resolution is limited by molecular weight,
threshold of soluble/insoluble molecular weight must be low.

Positive resist: Strong exposure & Weak Development
(Higher decomposition)

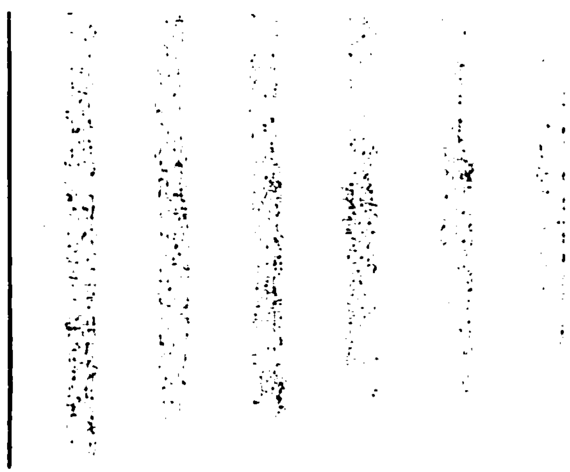
Negative resist: Lower molecular weight before exposure
(Strong exposure & Weak Development)

PMMA



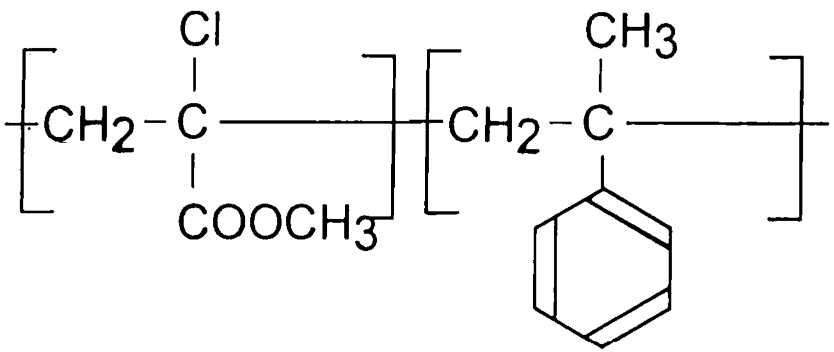
Polymethylmethacrylate (PMMA)

Higher resolution
Higher dose
&
weaker development



Period:	50 nm
Thickness:	20 nm
Dose:	1.8nC/cm
Development:	MIBK:IPA=1:9 45 sec
Rinse:	IPA 15 sec

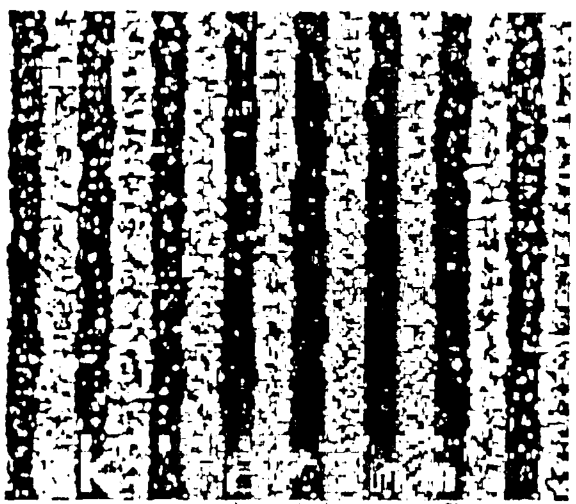
ZEP-520



Etching mask of Q-Wire laser
20nm thick SiO_2 film
Transfer by CF_4 RIE

PMMA: Low dry etch resistance

ZEP-520 (Nippon ZEON)
with 10 % C60 (fullerene)



Period:	50 nm
Thickness:	30 nm
Dose:	0.8nC/cm
Development:	MIBK:IPA=1:1 30 sec
Rinse:	IPA 15 sec

Exposure area for Quantum Wire lasers

Laser optical cavity (15 μm x 400 μm)

50 nm pitch , 0.8 nC/cm, 100 pA

↓

2 min / one cavity!

Actual devices

40 μm x 3.6 mm x 24 set

(2 % of 8 mm x 24 mm)

↓

15 hours / wafer

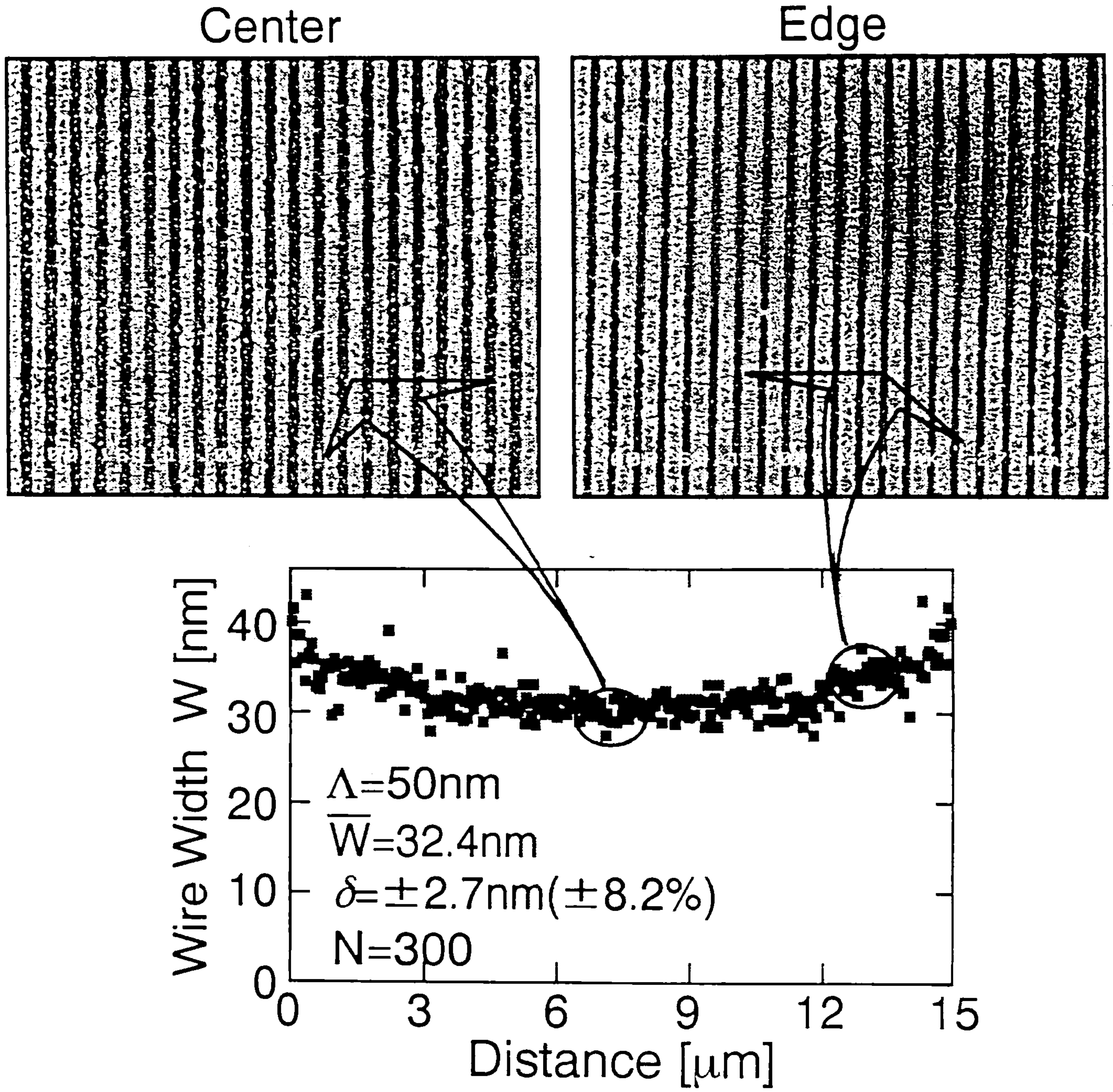
If LaB_6 cathode

5 pA for 5 nm beam

↓

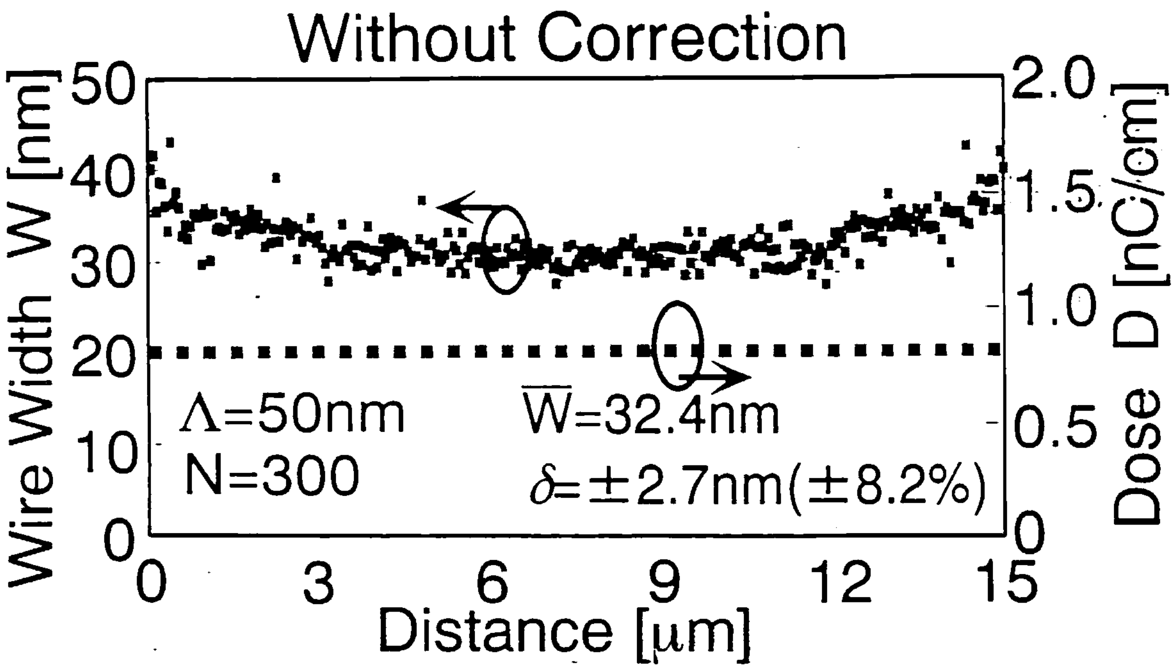
300 hours / wafer ~ 12 days

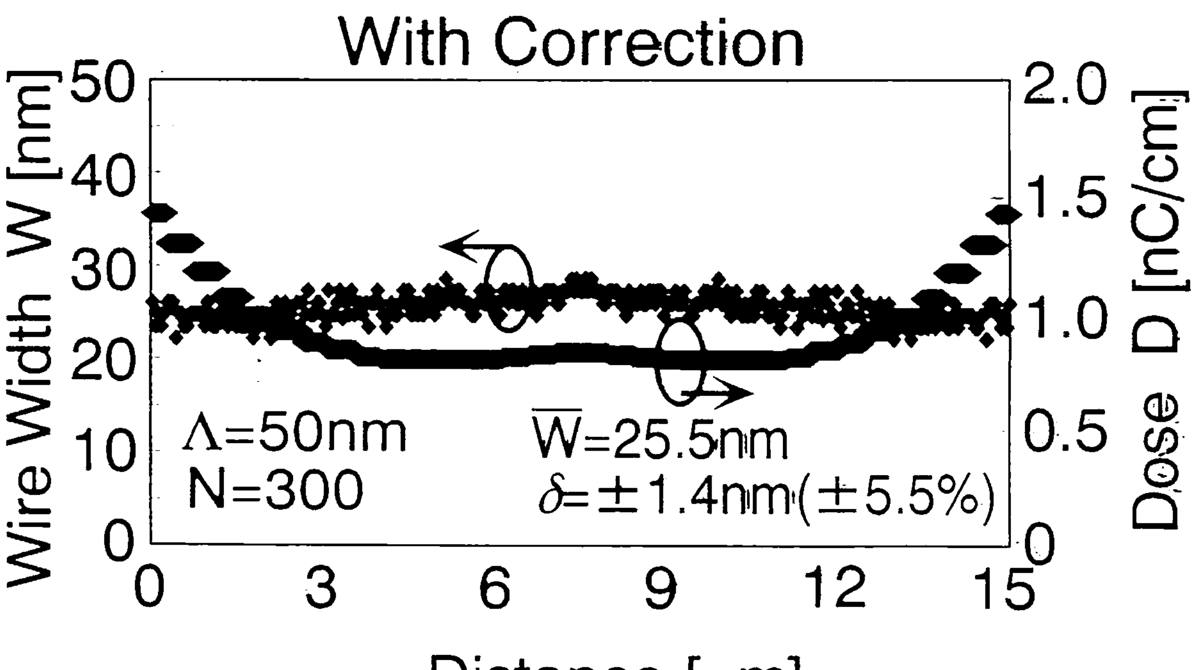
Size Fluctuation by back scattering



◎ Reduce the size fluctuation by dose control.

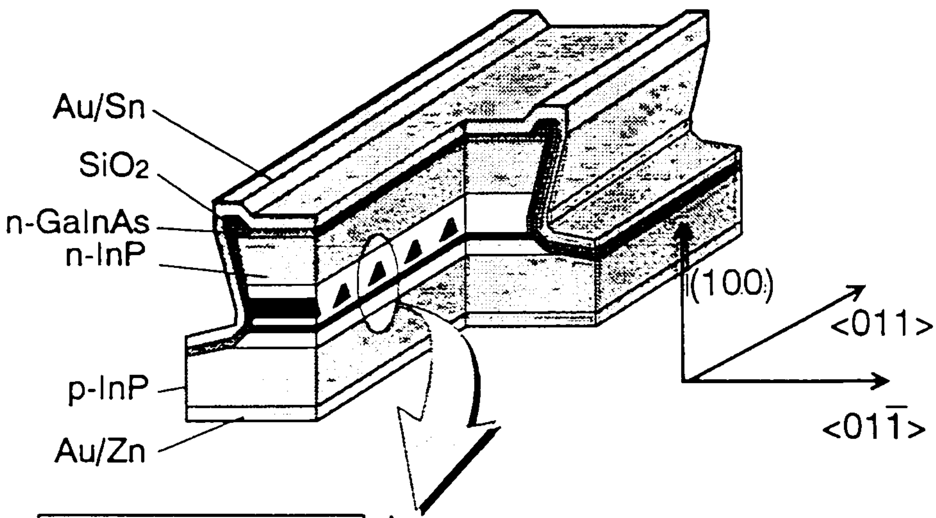
Size Fluctuation (Resist Pattern)

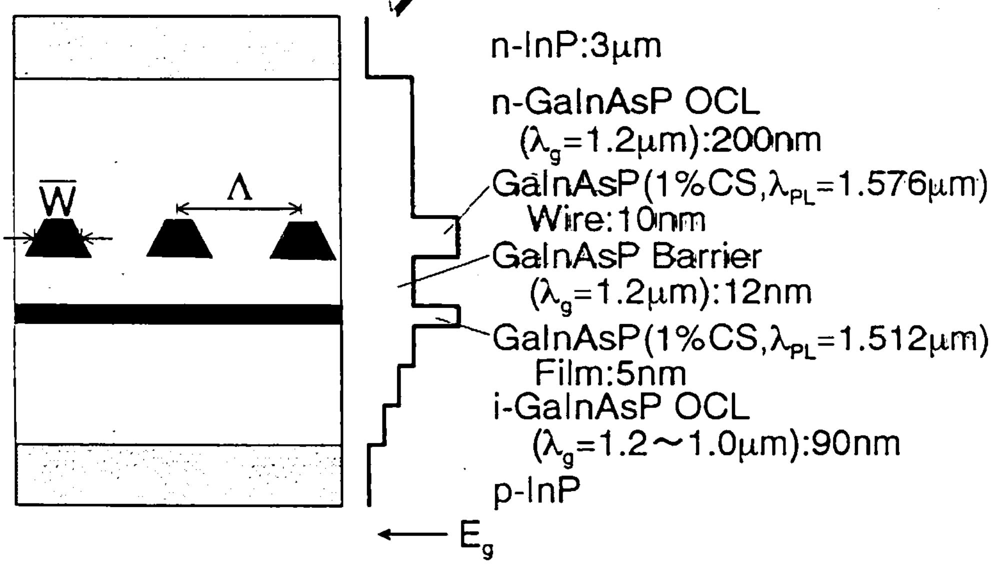


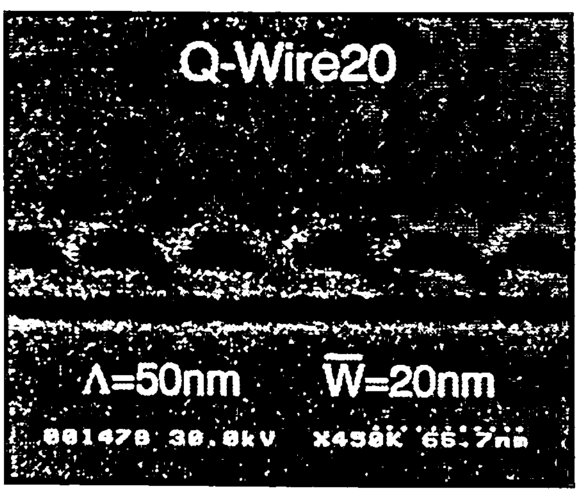


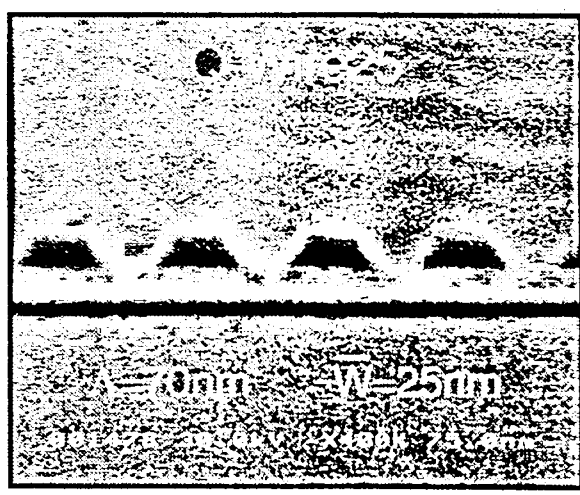
Reduced fluctuation : 2.7nm→1.4nm

GaInAsP/InP Quantum wire laser









Temperature Depe ıdence of Threshc 'ıd Current Density & Differential Quantum Efficiency

◎ T<170K

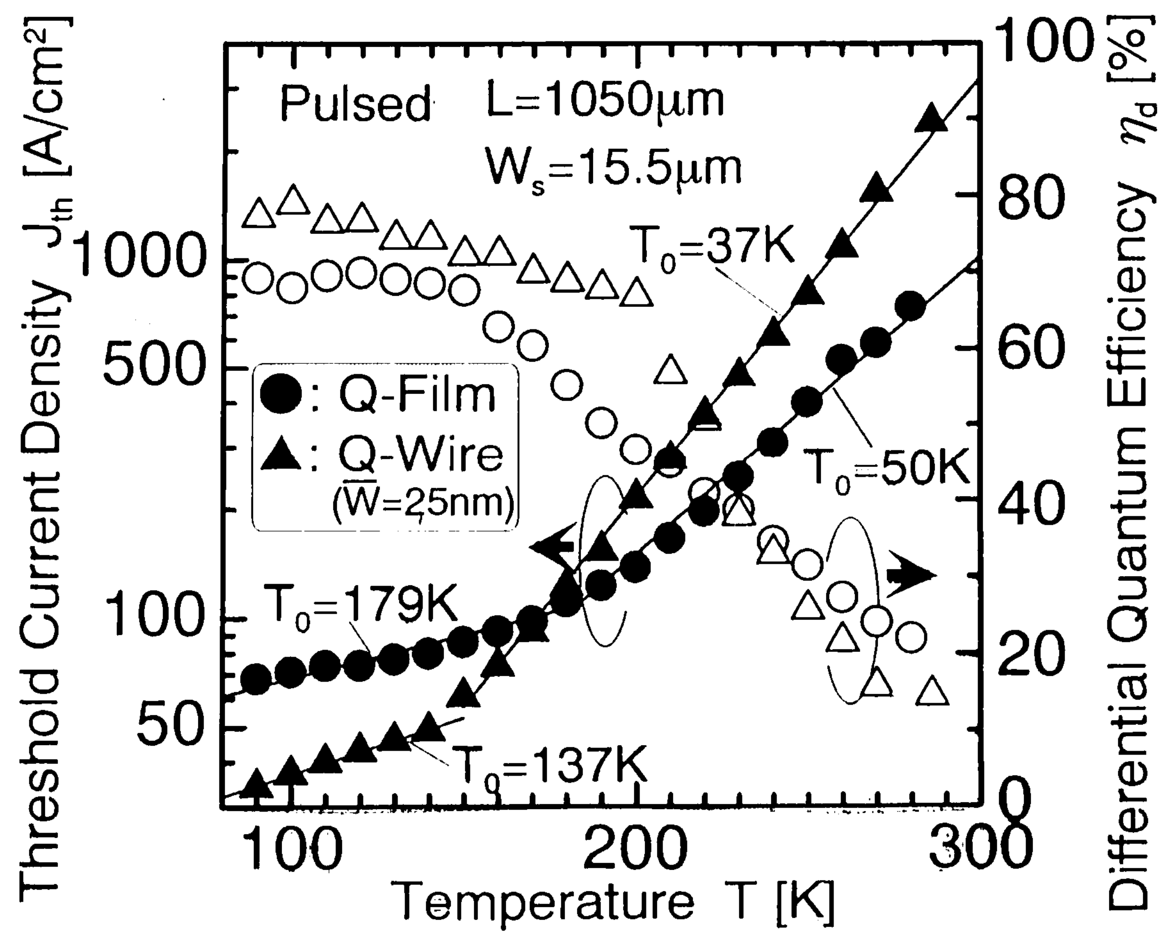
$J_{th,Q\text{-}Wire} < J_{th,Q\text{-}film}$

	J_{th} [A/cm²]	
	T=285K	T=90K
Q-Wire	2400	34
Q-Film	650	68

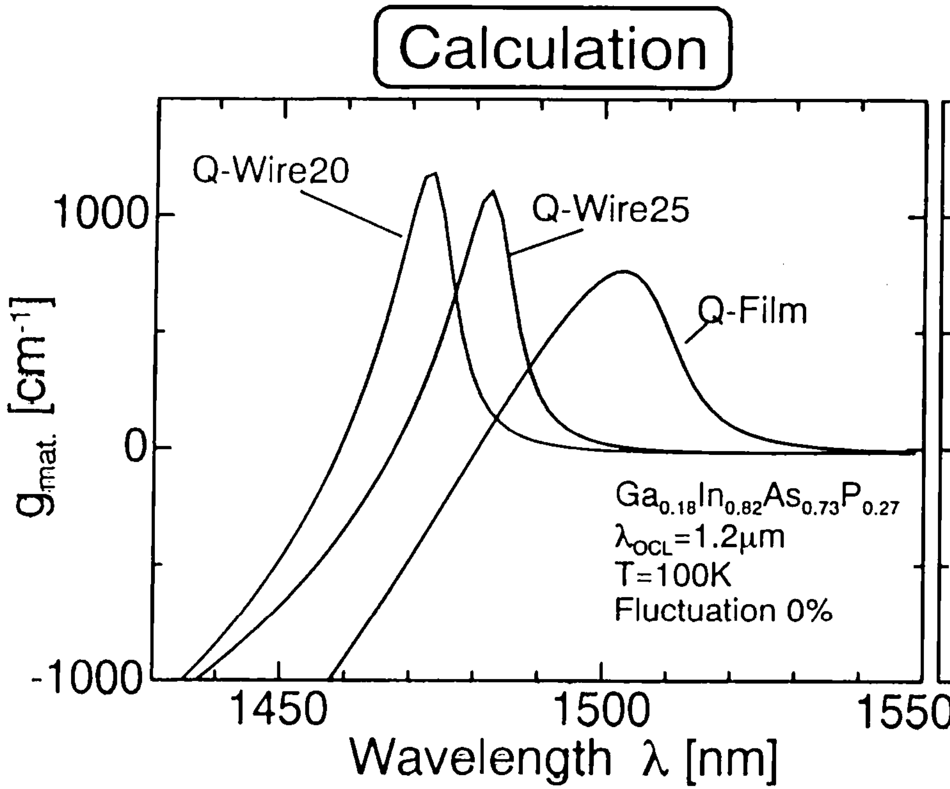
◎ T<220K

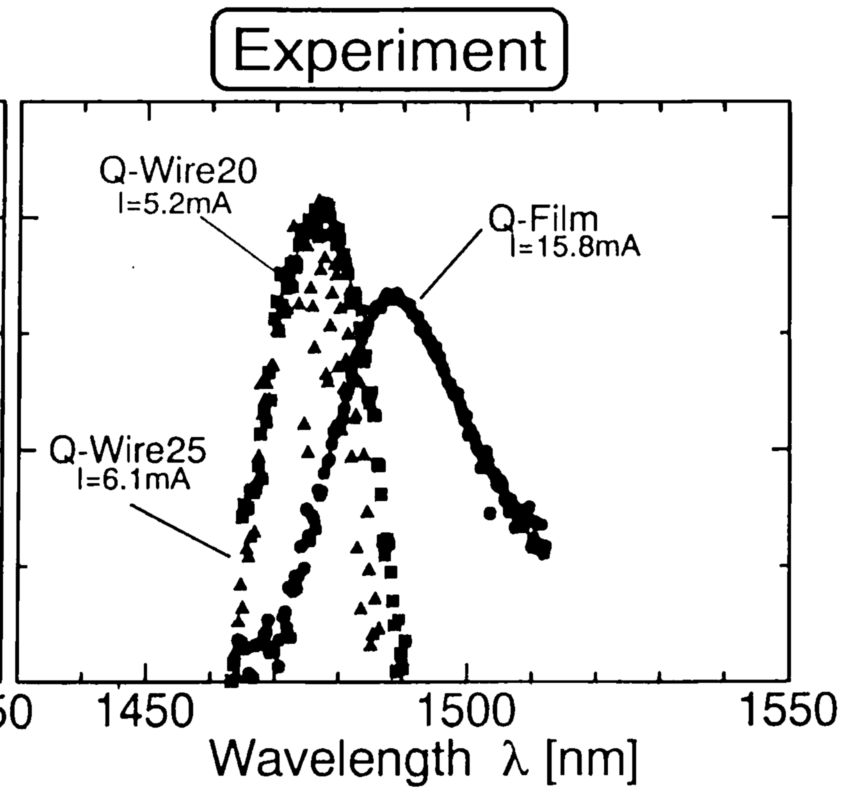
$\eta_{d,Q\text{-}Wire} > \eta_{d,Q\text{-}film}$

	η_d [%]	
	T=285K	T=90K
Q-Wire	15	77
Q-Film	18	69



Comparison of Gain Spectrum





	τ_{in} [psec]	N [cm^{-3}]
Q-Film	0.2	2.1×10^{17}
Q-Wire25	0.3	2.2×10^{17}
Q-Wire20	0.3	2.5×10^{17}

	Q-Film	Q-Wire25	Q-Wire20
Gain Width ($\Delta\lambda_{gain}$)[meV] at $0cm^{-1}$	14.0	9.68	10.8

$\Delta\lambda_{gain}$(Q-Wire) < $\Delta\lambda_{gain}$(Q-Film) ⇨ { Difference of Density of State; τ_{in}(Q-Wire) > τ_{in}(Q-Film)

Resist for Electron wave device

At present, One device/one chip (1 mm x 1 mm)
Two or several slits x 5 μm per one device

100 nC/cm x 100 pA → 5 sec per device

8 mm x 24 mm → 16 min

Higher resolution resist (even if it requires higher dose!)

Negative resist

phenol resin

polystyrene

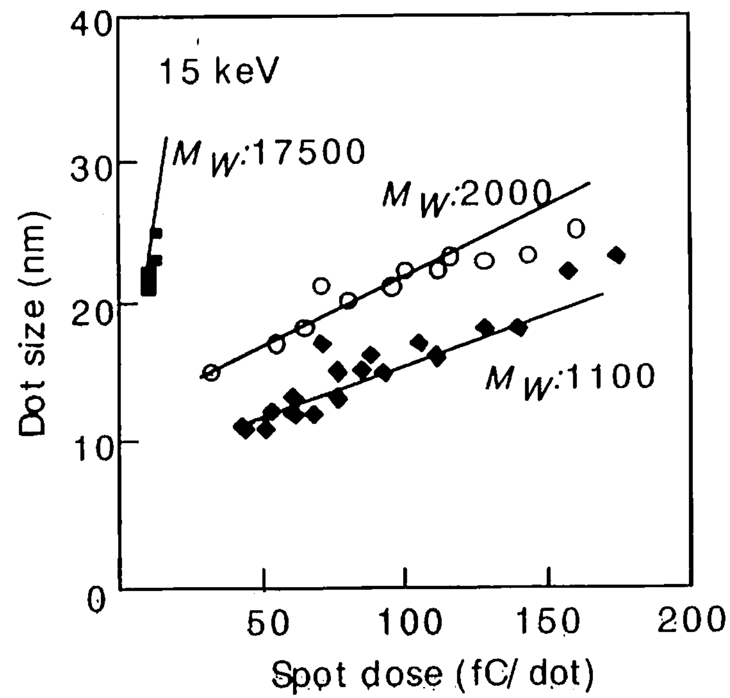
Poly(α -methylstyrene)

Higher resolution

Lower molecular weight (M_W)

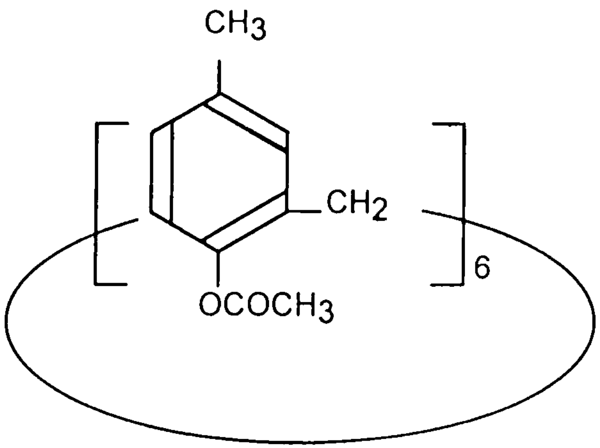
Lower dispersity of M_W

Dependence on M_W of polystyrene



(mono-dispersion)

Calixarene as EB resist

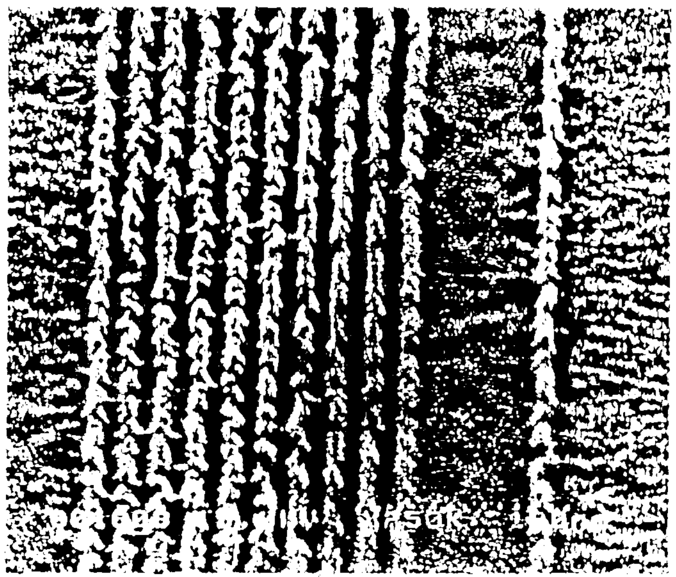


Calixarene

M_W:950

Mono-dispersion

(J.Fujita et al, JVST '96)



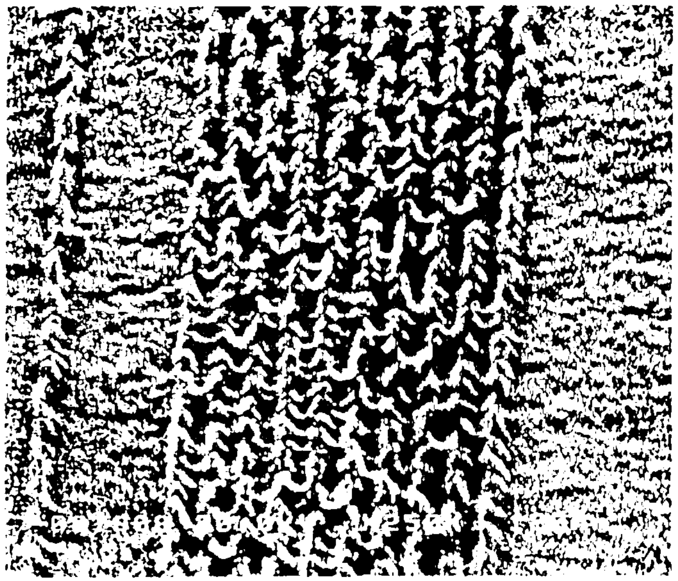
Period:	25 nm
Thickness:	17 nm
Dose:	32nC/cm
Development:	xylene 30 sec
Rinse:	IPA 30 sec

DEPENDENCE OF DEVELOPING TIME

25 nm pitch resist pattern in the early stage

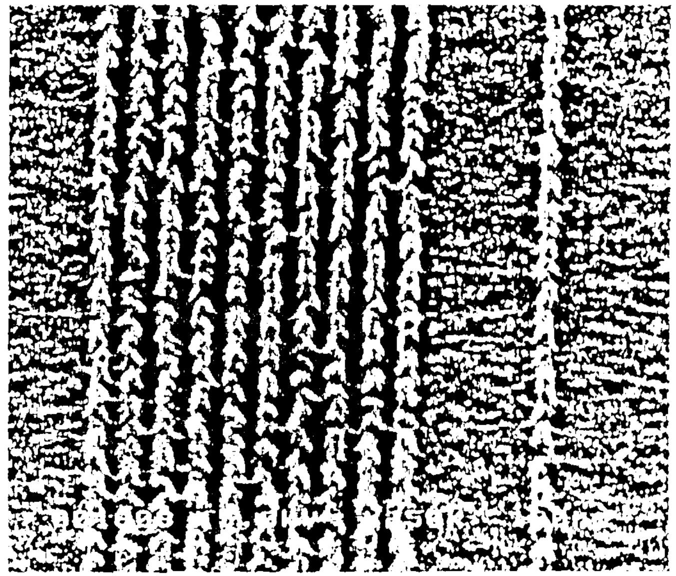
Developing time

70 sec



Large deformation
by Swelling

30 sec



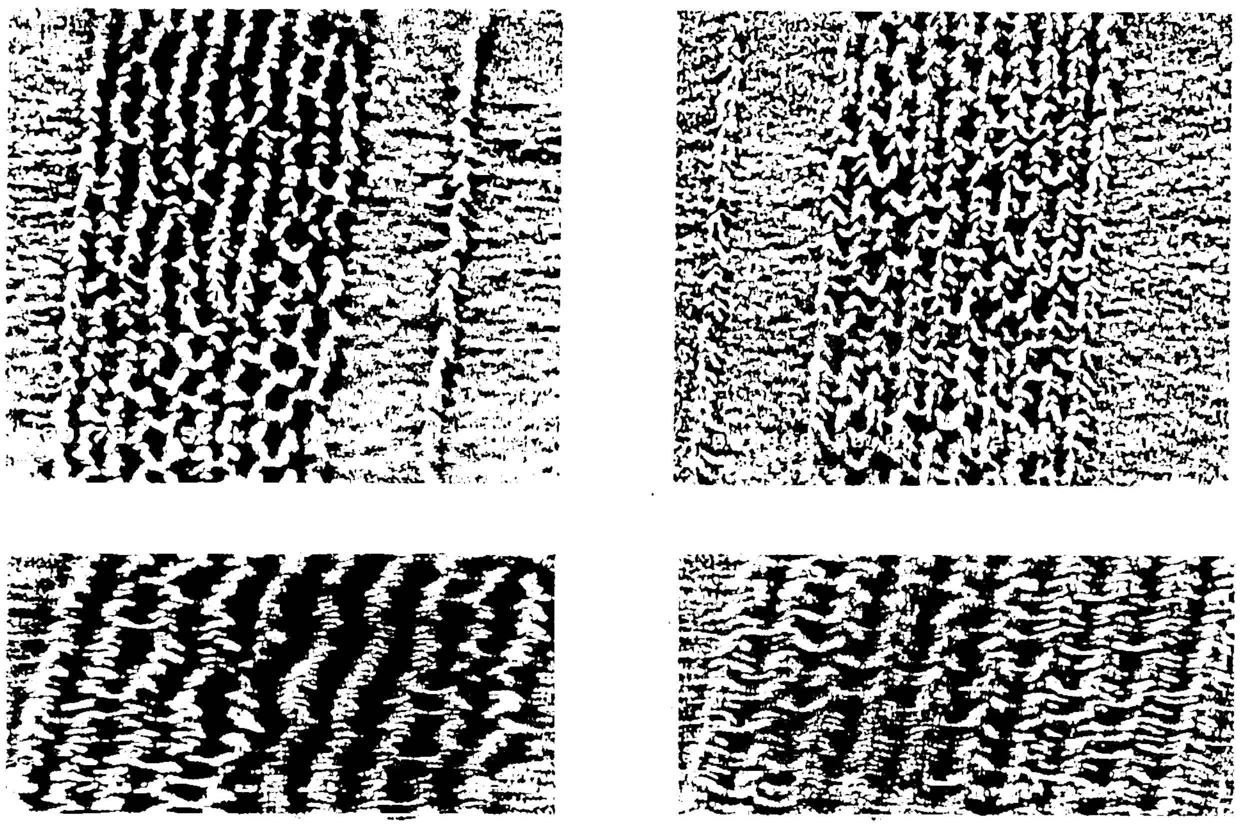
Small deformation

REQUIREMENT of ACCURACY of STAGE MOTION

25 nm pitch resist pattern in the early stage

Accuracy of stage position

5 nm | 0.62 nm



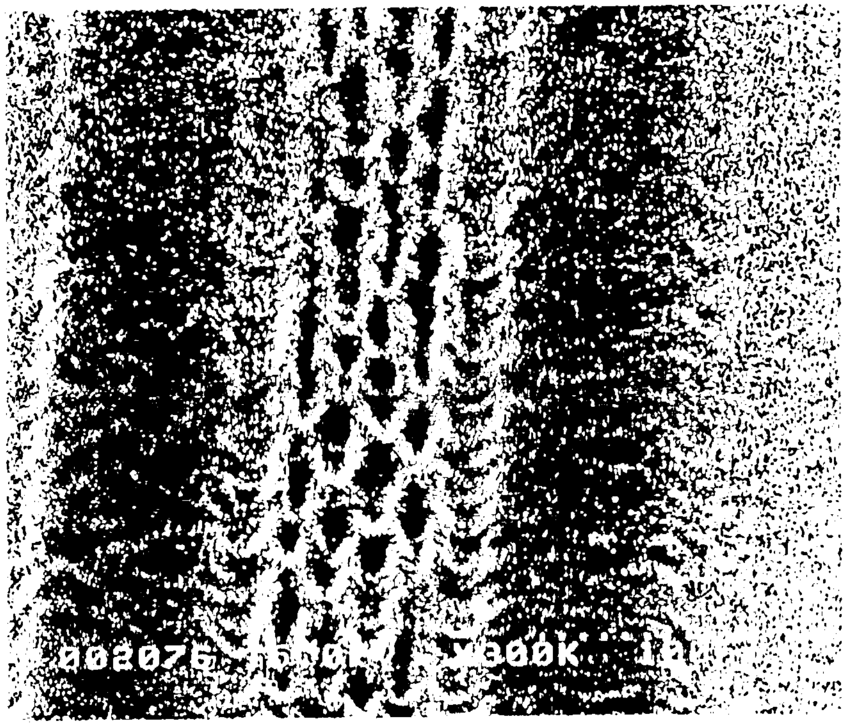
(SEM view with 20^0 Angle)

(Expand & Compress in depth)

Wavy ridge lines | Straight ridge lines

development:70 sec in xylene

20 nm PITCH RESIST PATTERN



Wavy pattern
Deformation by swelling defeats adhesion between the resist and the surface?

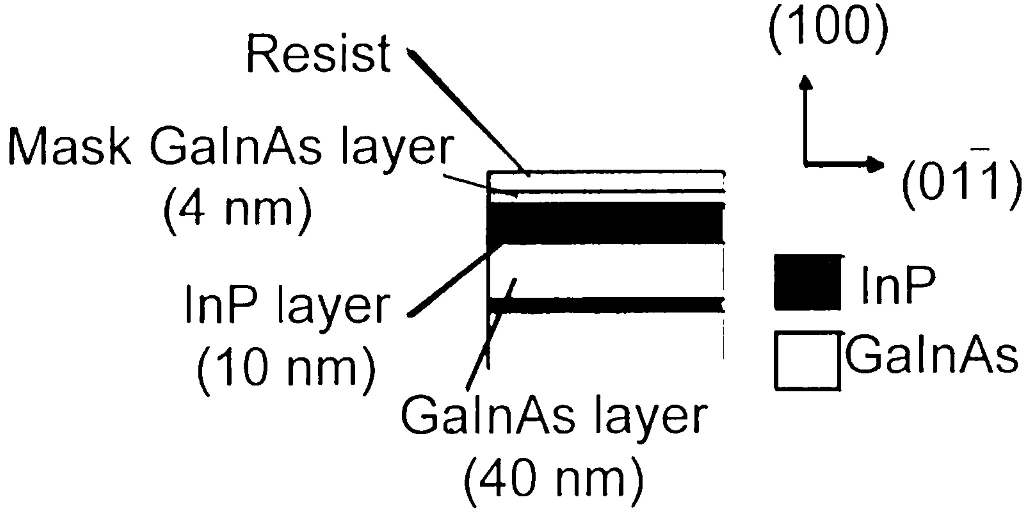
→Thinner resist?

TWO-STEP WET CHEMICAL ETCHING

semiconductor mask layer
selective & anisotropic etching

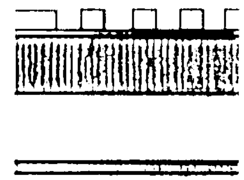
Inamura et al.,
Jpn. J. Appl. Phys.,
28 2193 (1989)

1.Crystal growth and resist coating



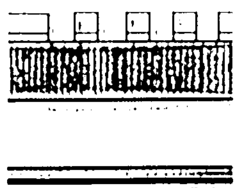
2.EB exposure and slight O_2 ashing

by RIE,
(10Pa, 0.45W/cm^2, 6sec, ~2-3nm etch)



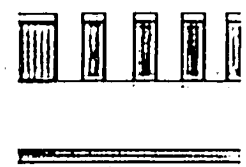
3.1st wet etching

citric acid:H_2O:H_2O_2=20:30:1 6-7sec

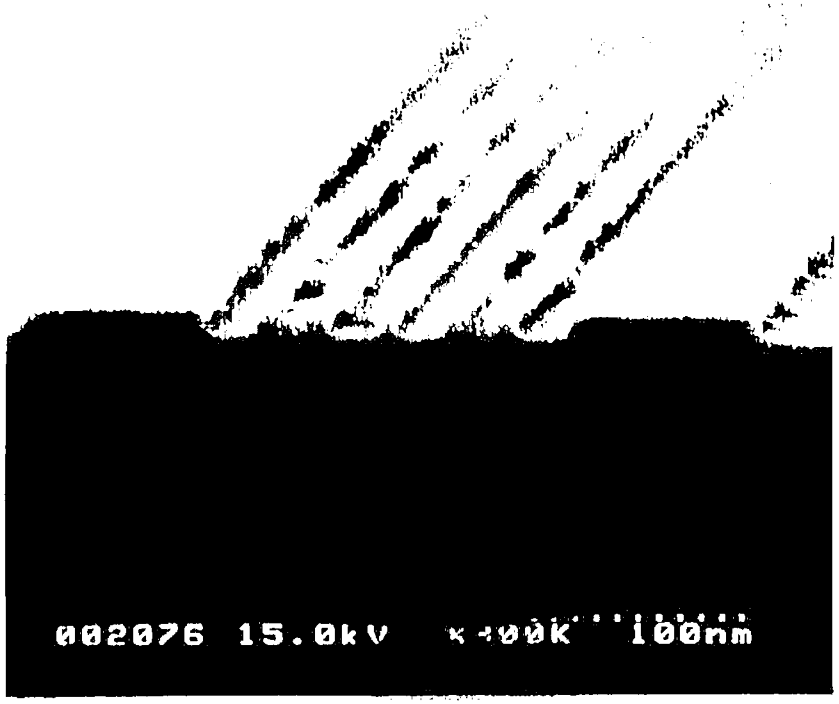


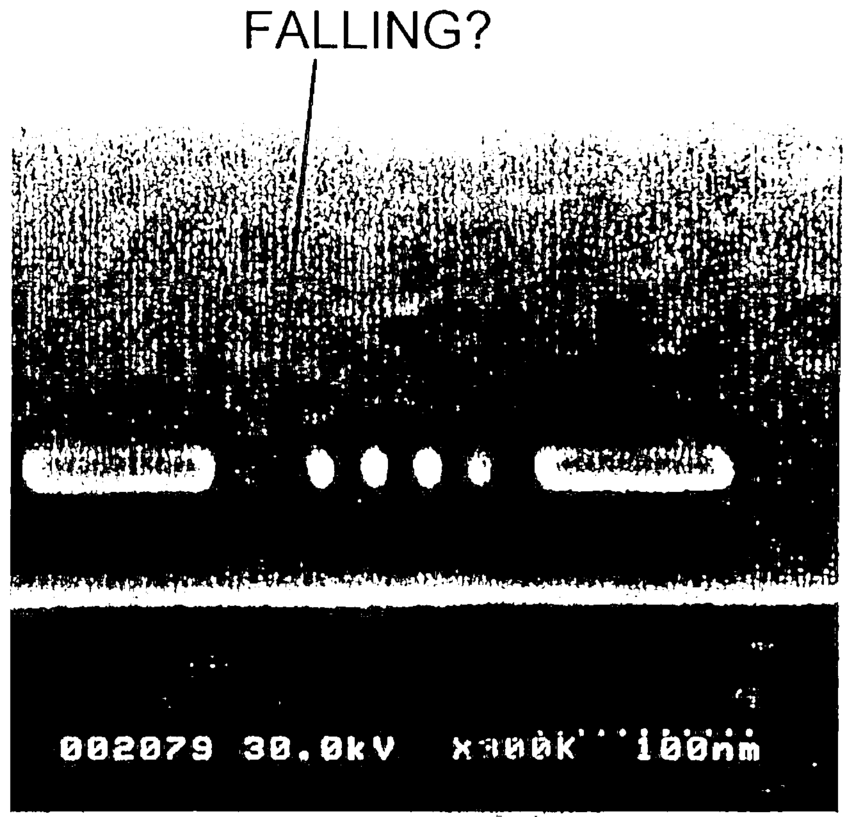
4.Removal of resist by O_2 ashing and 2nd wet etching

HCl:CH_3COOH=1:4 30 sec



25 nm PITCH InP PATTERNS and BURIED STRUCTURE





After GaInAs Buried growth

InP patterns

SEM view from cleaved facet

To prevent deformation before regrowth,
Sample was heated
under
tertiarybutylphosphine atmosphere

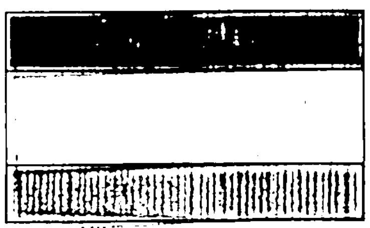
FOR FINE ELECTRODE

Single layer resist pattern
NOT SUITABLE for Liftoff process

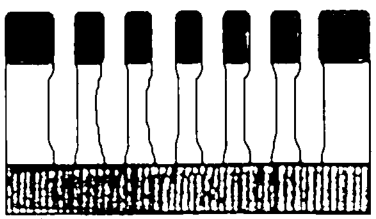
↓

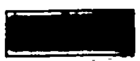
Double leyer resist

After coating of resist

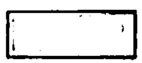


EB exposure, Development & O_2 ashing





ZEP520 with C60



PMMA

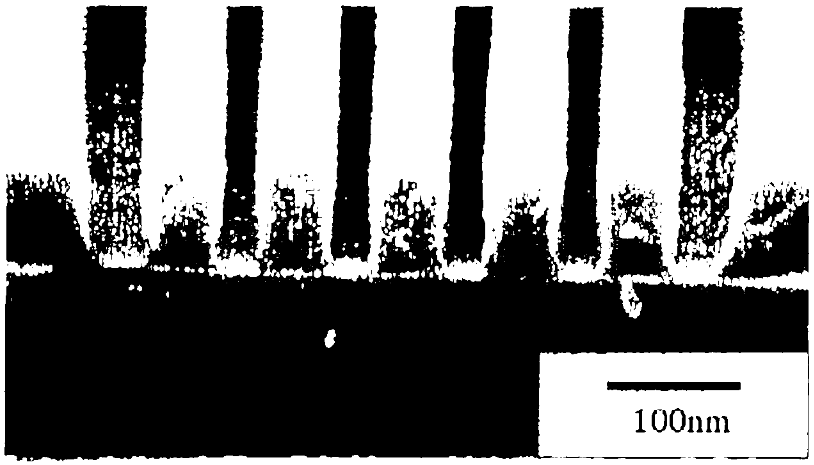
Difference of
Sensitivity
O_2 ashing resistance

↓

Good profile for liftoff

FOR FINE ELECTRODE

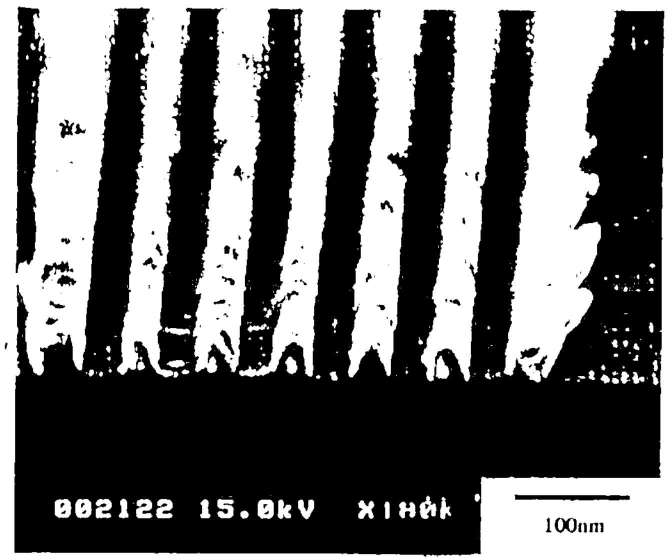
Resist pattern
after EB exposure,
Development
& O_2 ashing



Pitch 100 nm

Overhanged shape
Aspect ratio ~2

After liftoff



Pitch 80 nm

Metal: Au 40nm / Cr 10nm

Conclusions

Requirements of EBL machine

high current density and precise stage motion

50 nm pitch quantum wire laser

(resist:ZEP-520 with 10 % C-60)

Toward electron wave devices,

25 nm pitch InP pattern buried in a GaInAs structure

(resist:calixarene)

80 nm pitch Au/Cr electrodes

(resist: PMMA / ZEP-520 with 10% C-60)