微纳米加工技术与量子器件

82305100
fhyang@red.semi.ac.cn

LD LED

HEMT RTD

1

2

3

4

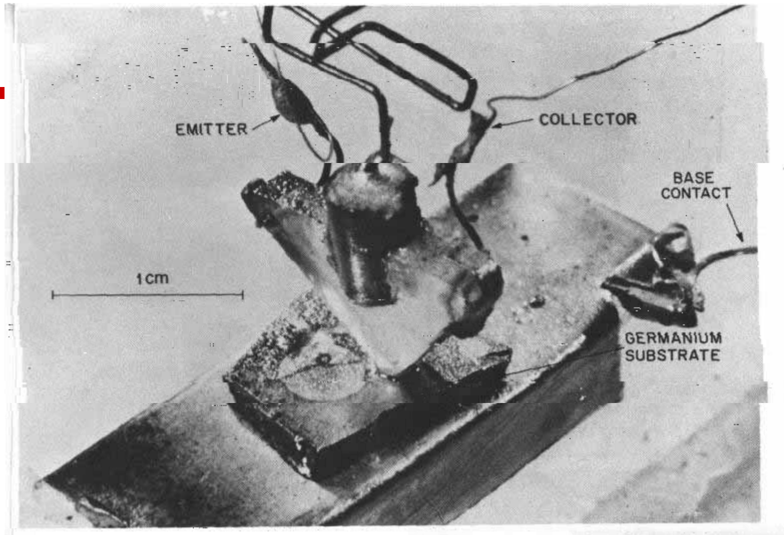
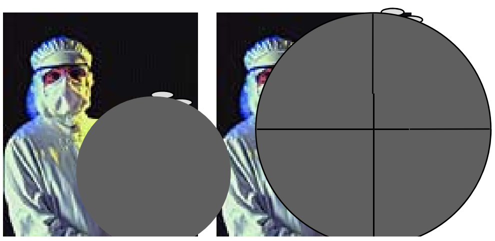
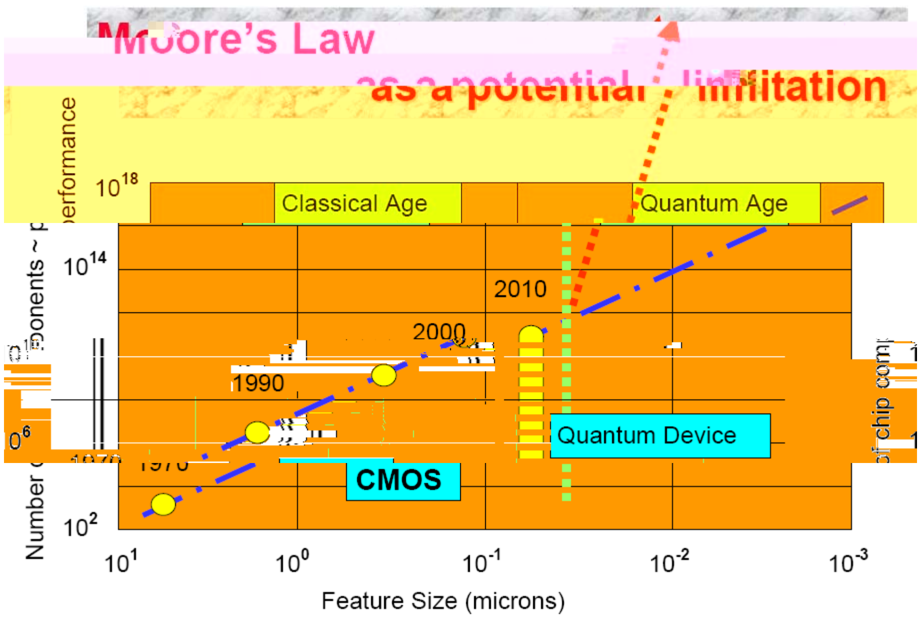


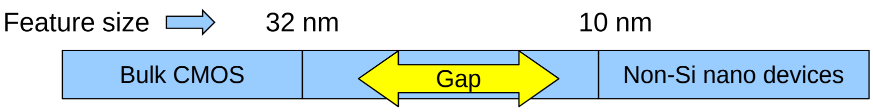
Fig. 1 The first transistor.[1]

When do we start planning for next wafer size transition?





Why Double-gate Transistors?

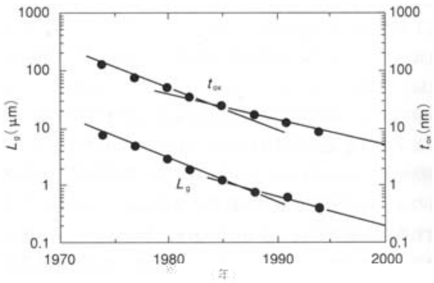


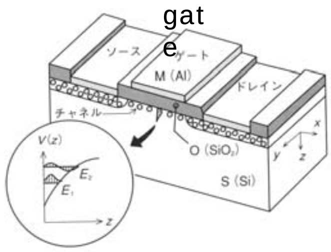
- DG-FETs can be used to fill this gap
- DG-FETs are extensions of CMOS
  - Manufacturing processes similar to CMOS
- Key limitations of CMOS scaling addressed through
  - Better control of channel from transistor gates
  - Reduced short-channel effects
  - Better Ion/Ioff
  - Improved sub-threshold slope
  - No discrete dopant fluctuations

Scaling Down of MOSFETS

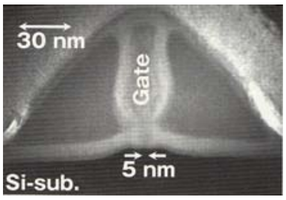
Gate length Lg (10 to Sub 100nm)
Oxide thickness t (200 to 2nm)

Lowered Voltage, Power & Cost
Raised Speed & Integration Level





Smallest MOS (Lg=5nm)(NEC



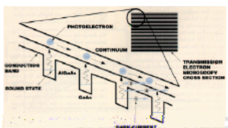
Short Channel Effects
to Be Controlled

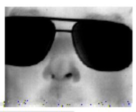
IR Sensors and Sources

- **Advanced Photodetectors**
  - Quantum Well Infrared Photodetectors
    - Use electronic band engineering and nanofabrication techniques
    - Multispectral IR imaging
  - Uncooled Infrared Detectors
    - Uses nanofabrication and advanced materials

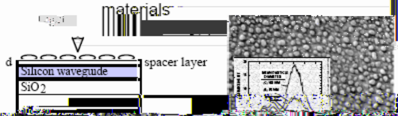
ed Detection
hanced Detection
etection by 20X

Quantum Well Infrared Photodetectors



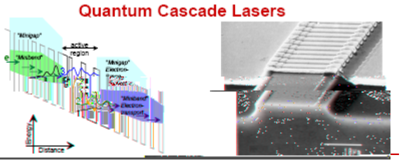


Nanoparticle Enhanc
- Nanoparticle-Enh
  - Increase light d



- IR Lasers for Target Designation and Countermeasures
  - Objective: Compact, pulsed, high power 300K IR lasers
- IR Lasers for Agent Detection
  - Objective: Tunable or multi-wavelength, single mode IR lasers

Quantum Cascade Lasers



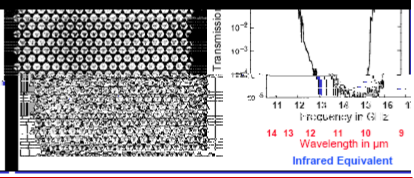
Photonic Crystals

- **Photonic Crystals**
  - "Designer Mirrors"
    - Periodic arrangement of dielctrics and/or metals

[redacted]

  - 2 D Photonic Crystals
    - Used in nanolasers, optical fiber
  - 3 D Photonic Crystals
    - Reflect radiation
      - From all directions
      - From all polarizations

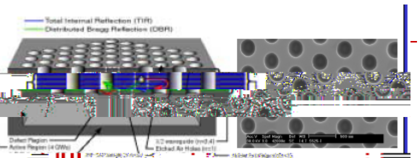
1D Photonic Crystals
John Joannopoulos, MIT

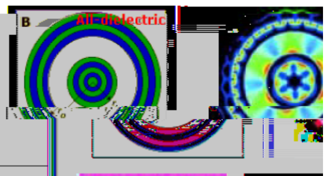


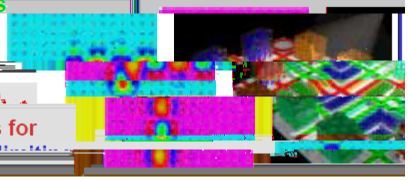
20100401 9

Photonics

- **Lasers**
  - Smallest possible laser cavity
  - Low Threshold
- **Light Emitting Diodes**
  - Improved emission efficiency
  - Improved collimation
- **Waveguide**
  - Omniguide fiber and coax
  - Photonic crystal fiber
- **Integrated Photonics**
  - Optical routing, filtering, and processing on a chip
- **Laser Eye/Sensor Protection**
  - Enhanced nonlinearities for optical limiting

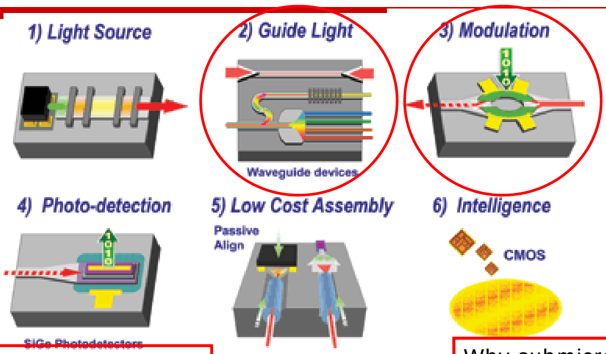






20100401 10

Key Devices in Silicon PICs



Why Silicon
- High index contrast
- CMOS process compatible
- Low cost

Why submicrometer
- Strong optical confinement
- Ultra-small bend radius
- Small footprint
- Large-mass integration

Optical nano-circuits and nano-devices

"Optical nano-circuits and nano-devices can play a very important role in the future of science and technology,"

one will be able to achieve remarkable miniaturization. By using optics in nano-circuits and nano-devices, instead of conventional electronics, one would be able to increase the bandwidth of operation, which in turn would provide a higher data rate and significantly larger data storage."

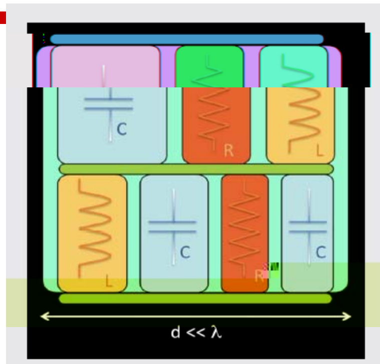
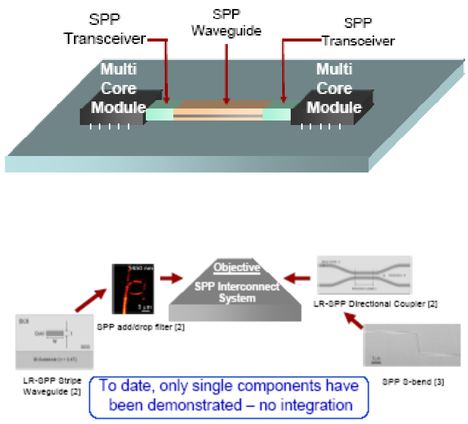


Figure 1: An example of optical nanocircuit. Several nanostructures arranged next to each other at the nanoscale could become the present electronic circuits ...

Surface Plasma Polariton

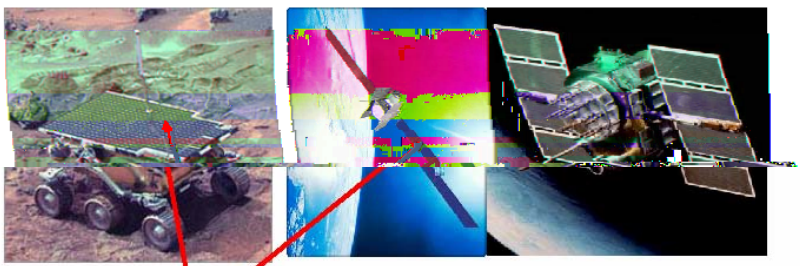
Interconnect Research Direction and Goals:

- **Plasmonic research is in its infancy. A specific application is for use in chip-to-chip interconnects, however it also has promise for companion technologies such as metamaterials (negative indices of refraction for super-resolution in the optical regime).**
- **Research goals are to demonstrate chip to chip data transfer and develop components necessary to a fully functional SPP interconnect system.**



Spectrolab A Boeing Company ISO9001:2000 REGISTERED — A New Solar Cell Technology

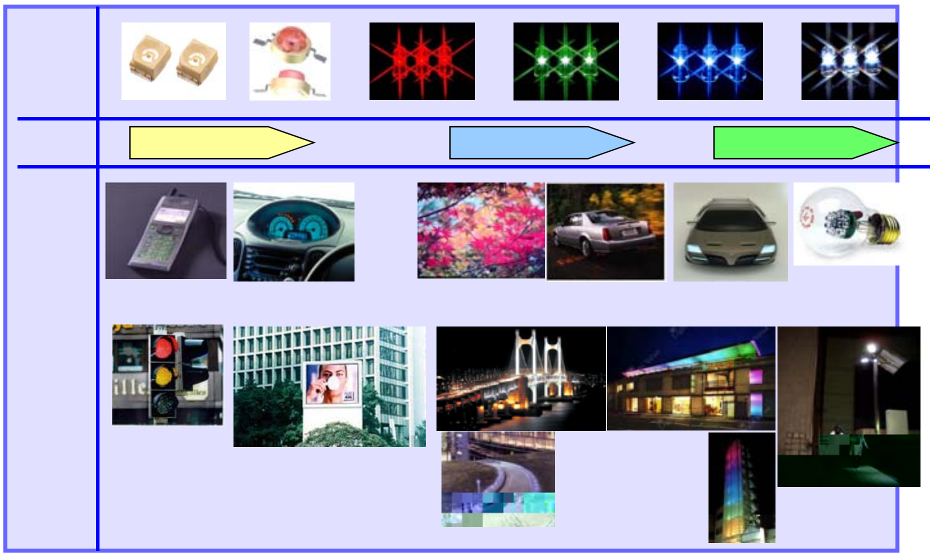
Scientists were working very hard to introduce "multi-junction" solar cells into the domain of solar energy, building on the "dual-junction" technology that was developed by the DOE.



8

High-efficiency solar cells made of III-V materials used to power spacecrafts

-



20100401 - 15

微纳米加工技术与量子器件

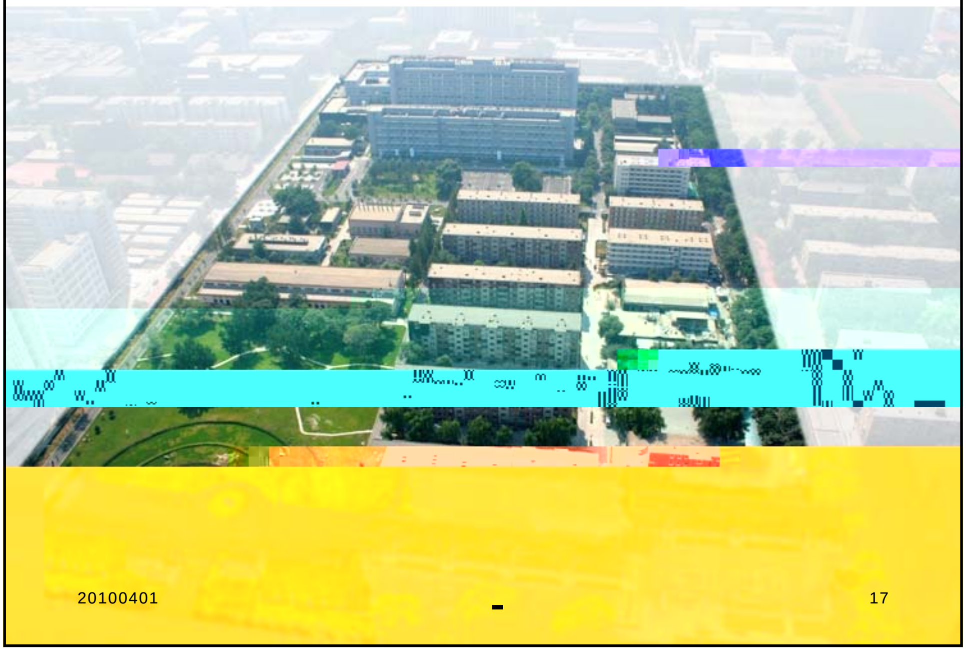
1

2

3

4

20100401 - 16



1.2 3000 1700

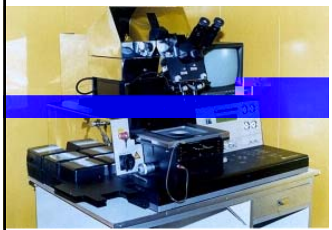
1100 8000

2004

MA6

III-V Si

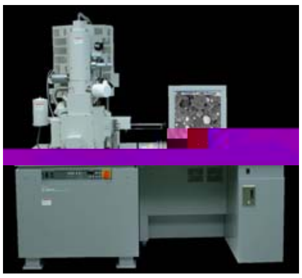
SiO2 PECVD



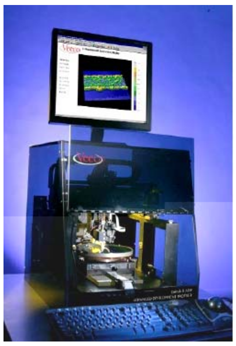
XRD SEM

LED

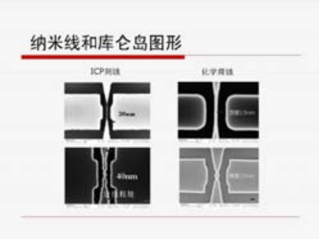
SEM

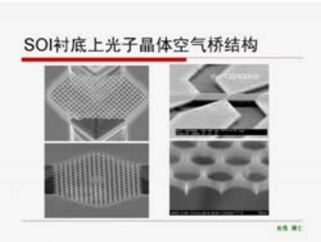


HR-XRD

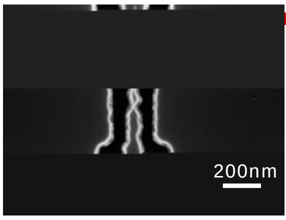


973 863



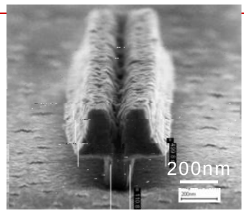


MEMS

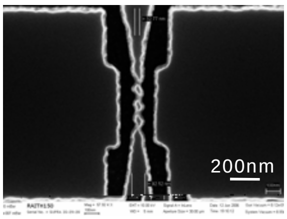


单量子点

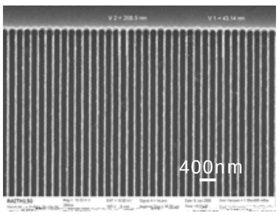
单量子线



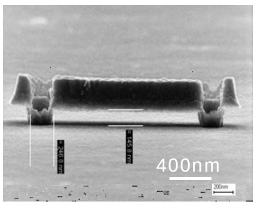
型门



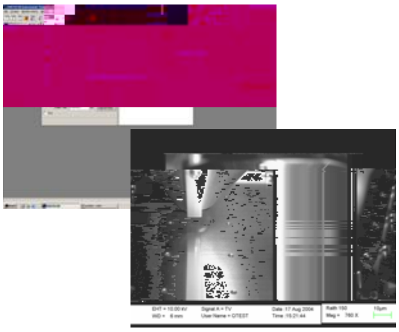
多量子点



量子线阵



空气桥



- (<0.5µm)
- 6
- (10-20nm)

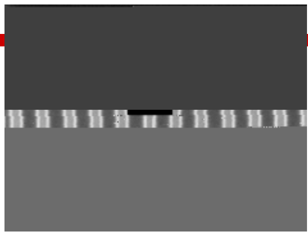
- ,
- 10 10 mm²
- SEM

(: 20nm)

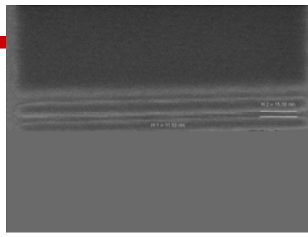
- 200eV-30keV
- ( )
- 6 ( )
- 0.5µm-1000µm
- 10MHz
- PC SEM
- GDSII

25

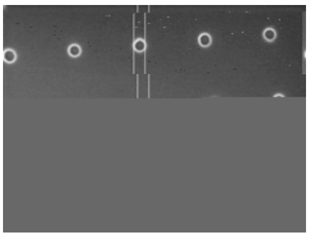
PMMA :100nm | PMMA : 50nm



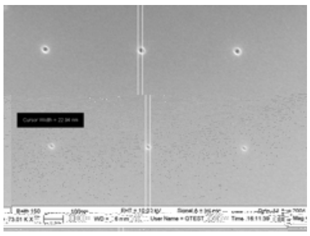
: 53.5nm



: 11.5nm



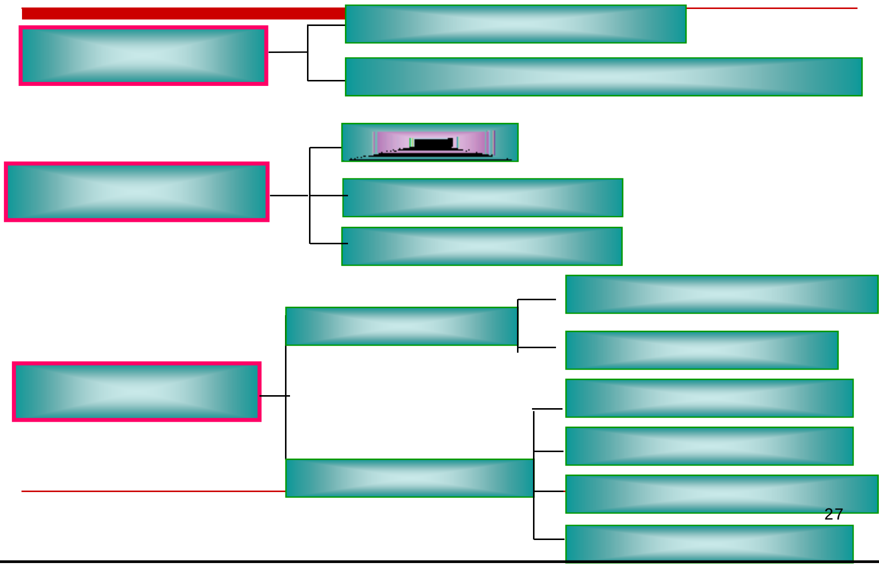
: 85.6nm



: 22.4nm

26

Nano-technology Applications in IOS



27

MA6

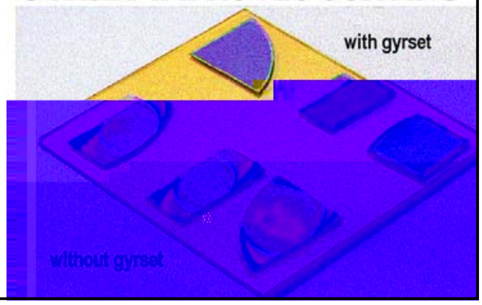
SUSS MA6

28

SUSS匀胶机

特点：1、盖式载片台 2、减薄厚胶边装置 3、均匀性小于3%

GYRSET IMPROVES COATING



Microwave Plasma Batch System 300

Damage-free Resist Ashing and Wafer Cleaning for Semiconductor and Microelectronics Manufacturing

- Easy Resist Removal following High dose Implant or Dry Etching
- Lowest Cost-of-Ownership of all Asher Technologies
- High Productivity, Simple Operation
- 200 mm Wafer Capability
- Minimum footprint, Flushmount Cabinet
- Microprocessor Controller

Applications:

Oxford ICP (III-V)

- ICP(Inductively Coupled Plasma)
- ICP

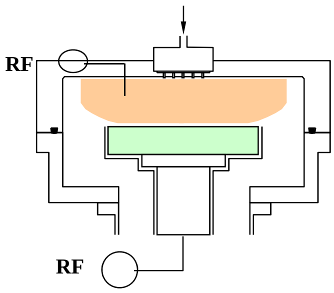
  (MEMS)

  LED

  GaN

Oxford ICP (III-V)

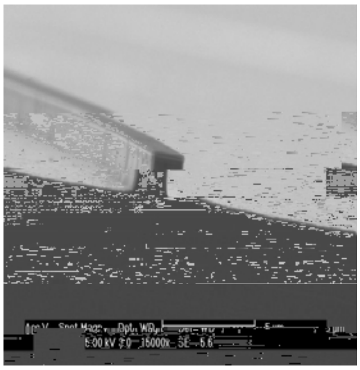
Oxford ICP (III-V)



ICP

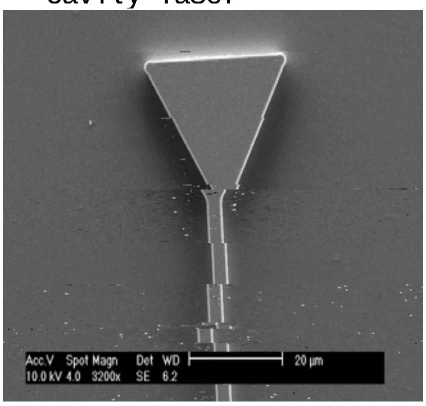
Oxford ICP (III-V)

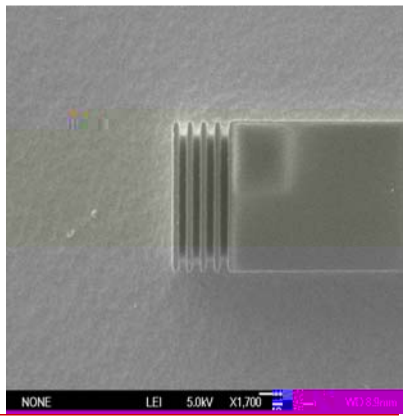
- Cl2 BCl3 CH4 GaN AlGaN GaAs InP InGaAs InGaP/AlGaInP InGaAs/InGaAsP
- >85 deg <+/-5%

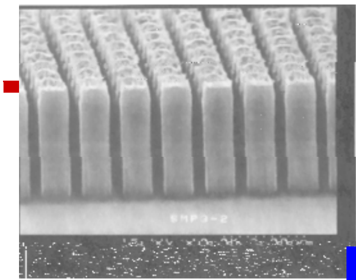


InP SEM

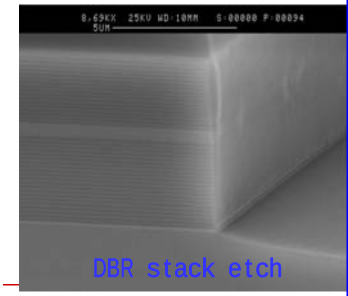
InP based triangle cavity laser



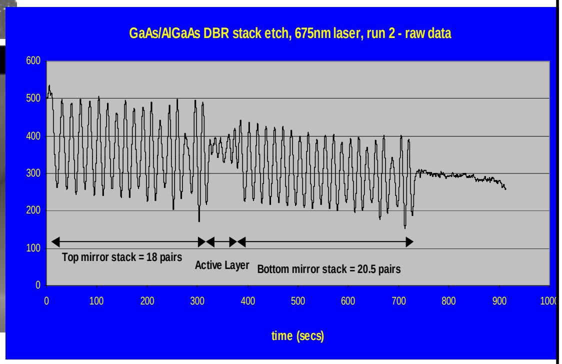




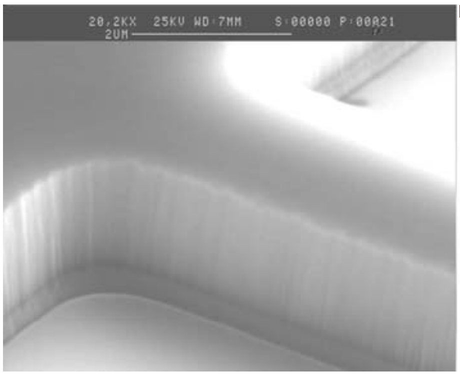
GaAs e/r > 0.3 µm/min
Sel to Oxide >10:1, Sel to resist > 5:1
Sel GaAs:AlGaAs 1:1
Anisotropic profile, Smooth sidewalls
Clean etch surface
Laser interferometry to monitor depth



DBR stack etch



ICP AlGaN/GaN etch



GaN e/r > 0.6 µm/min

Sel to Oxide >7:1

Anisotropic profile

Smooth sidewalls

Clean etch surface

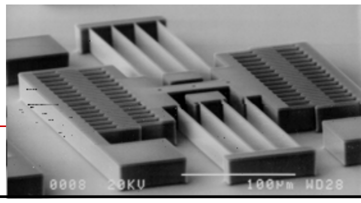
System100 with ICP180 source

- SOI

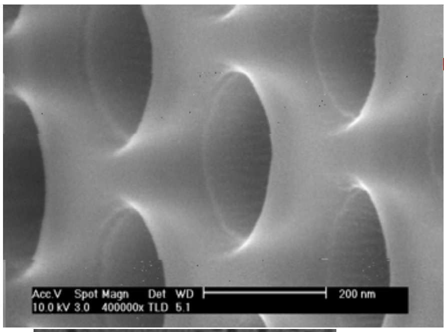
  >18 µm/min

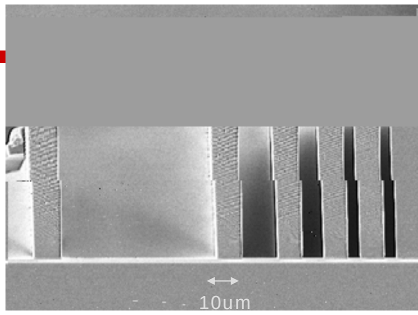
  .
- MEMS MOEMS

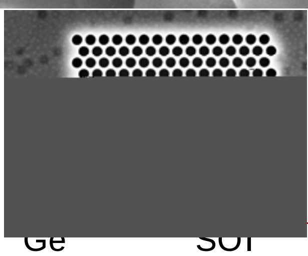
  ,



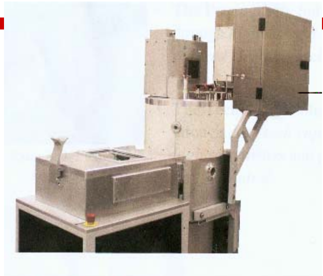
SOI







Ge SOI



1

2 Multipolar Magnetic Confinement

3

1 AWG -

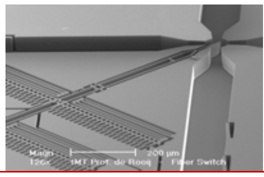
2 Si

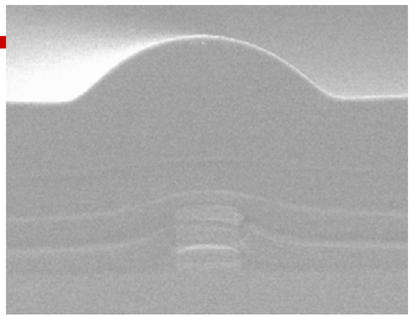
3 MOEMS

4 Si

5

Actuator, Grooves, Mirror





- AWG Ge 6um 16um
  SiO2 BPSG
  6um

OPTOFAB3000

-
-
-
-

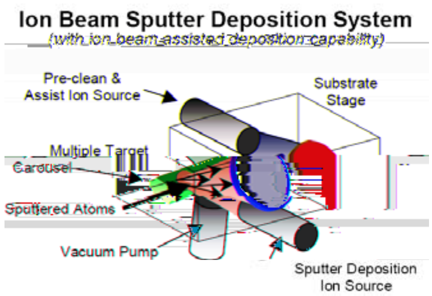
1)
2)
3)

Multi-layer interference filters

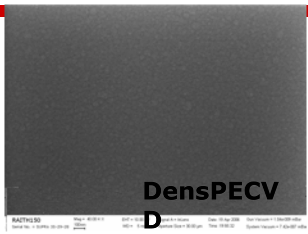
Optofab3000 (IBSD)

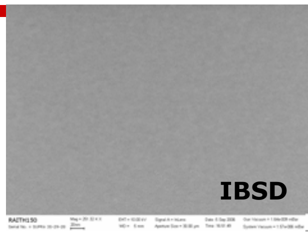
- 1
- 10-20eV 100
-

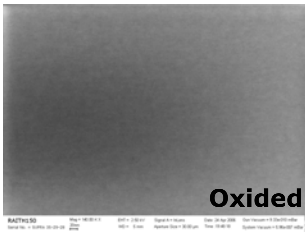
Material	Deposition rate
SiO_2	2.5Å/sec
TiO_2	3.1 Å/sec
Ta_2O_5	5.5 Å/sec
Al_2O_3	2.5 Å/sec
ZrO_2	3.1 Å/sec



SiO_2 :







IBSD SiO2 SEM

SiO_2/Ta_2O_5 GaInNAs/GaAs RWG

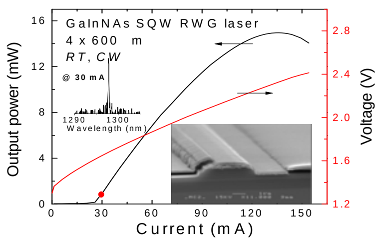


Fig. 1. RWG laser without coating

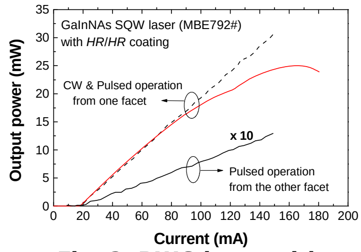
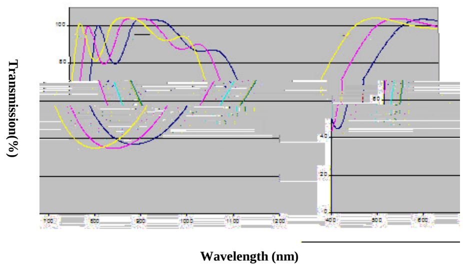


Fig. 2. RWG laser with coating

MBE792#	J_{th} (A/cm^2)	d	I @ thermal rollover
Without HR coating	25	0.19	130 mA
With HR coating	18-19	0.23	160 mA

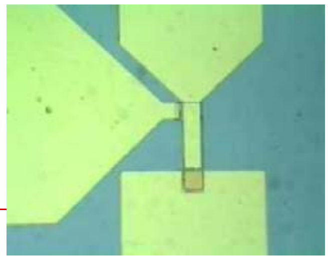
0.48H/0.80L/ 1.16H/1.89L/ 2.11H/1.70L/ 2.21H/0.51L



(HL)= λ/4 Ta_2O_5/SiO_2 λ=532nm

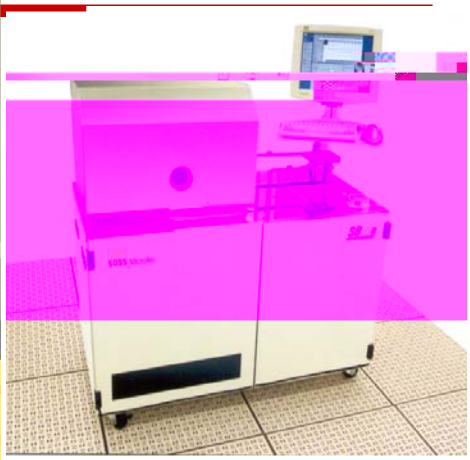
	532nm	1064nm
Run 1	93.3%	78.1%
Run 2	99.8%	94.7%
Run 3	99.49%	99.40%

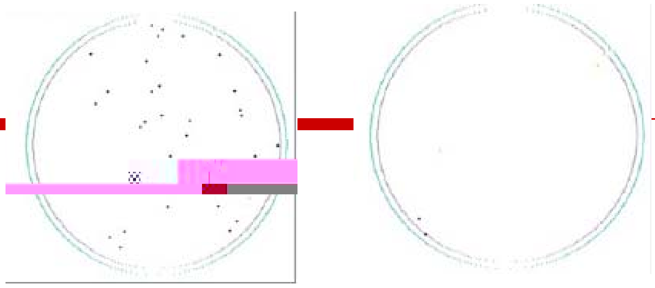
- 1
- a.
- b.
- 2
-



CL200

SB6

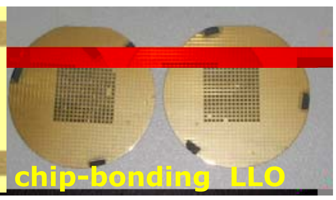




2in Si-Si
95

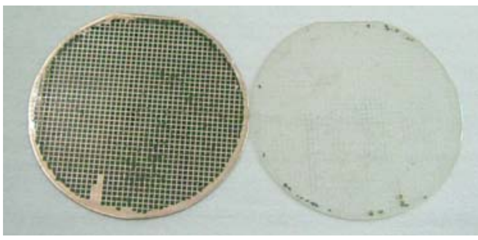
2in Si InP
85

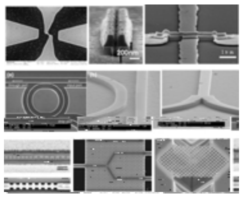
Wafer Bonding Technology



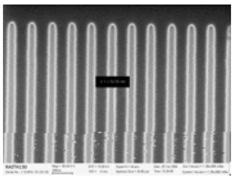
wafer-bonding on conductive Substrate

2 inch Sapphire lift-off
Yields is higher than 95%.

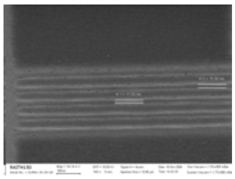




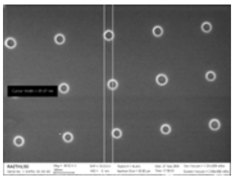
1



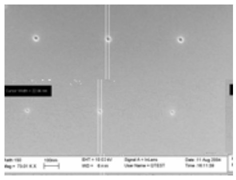
: 53.5nm



: 10.5nm

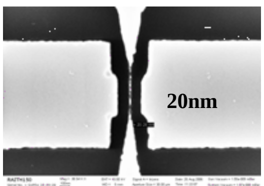


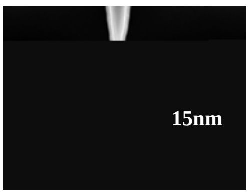
: 42.8nm

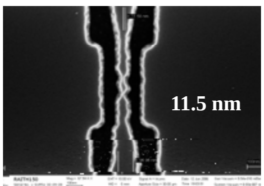


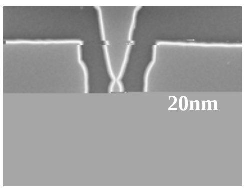
: 11.2nm

2

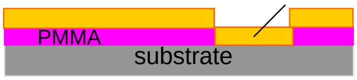


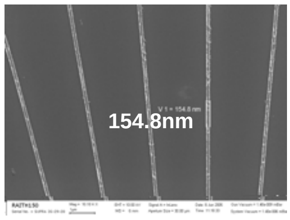


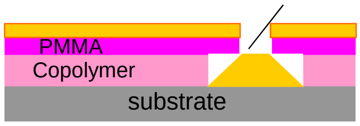


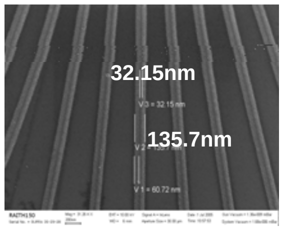


3

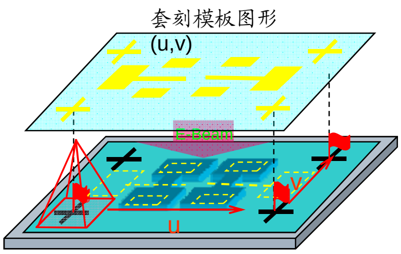

PMMA
substrate


154.8nm


PMMA
Copolymer
substrate


32.15nm
135.7nm

4


套刻模板图形
(u,v)
u
v

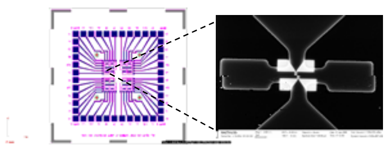
■

1.

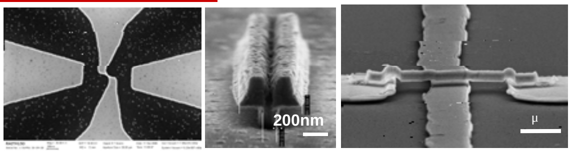
2.

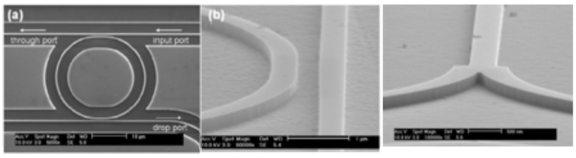
➢

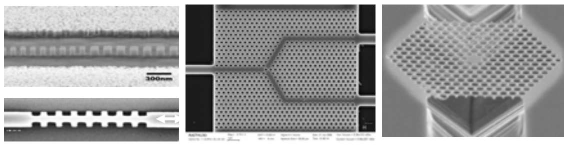
■



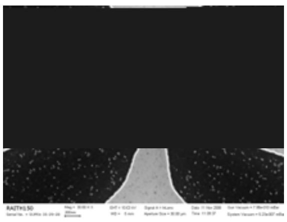
➢



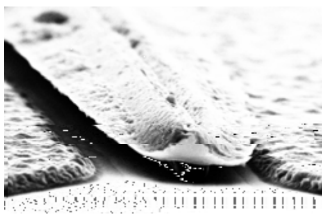




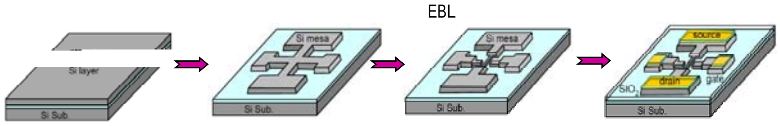
SOI



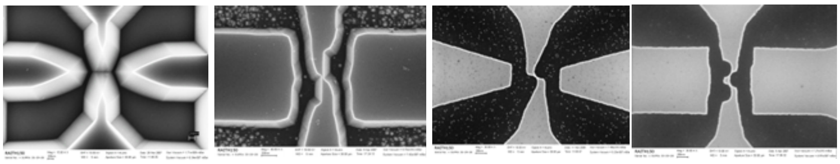
GaN



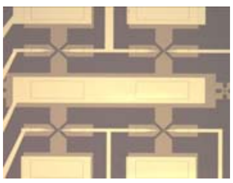
□

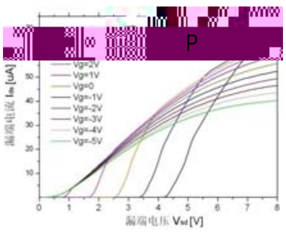


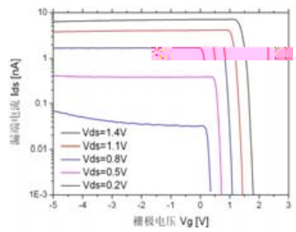
□

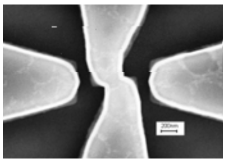


QPC 550nm   QPC 150nm   QPC 20nm   QPC 20nm

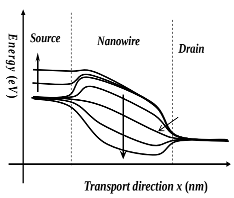








875 C

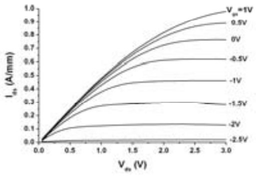


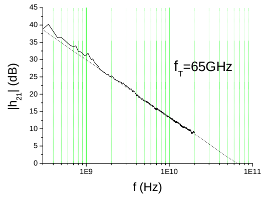
➢ 输出特性显示：在耗尽状态下，热电子电流的开启电压依赖于点接触结构处的势垒变化。

➢ 转移特性显示：亚阈值斜率达到了75mV/dec，接近了CMOS晶体管理想开关状态60mV/dec 。

最大电流密度为980mA/mm

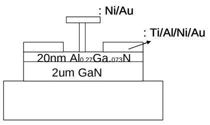
直流偏置: ,

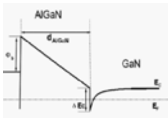




AlGaN/GaN HEMT

➢ Ids

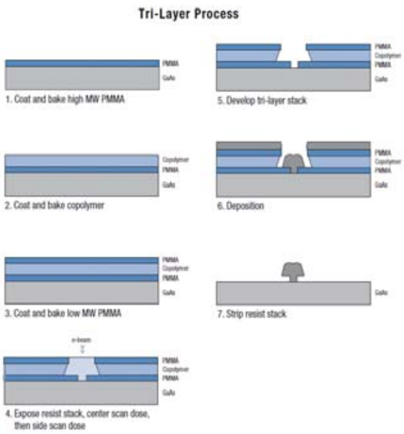


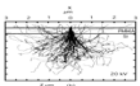


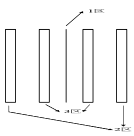
C_{gd} L_g

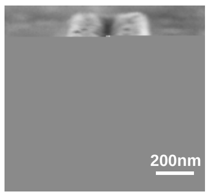
➢ Lg=0.18um T 10
65GHz.

GaN HEMT T





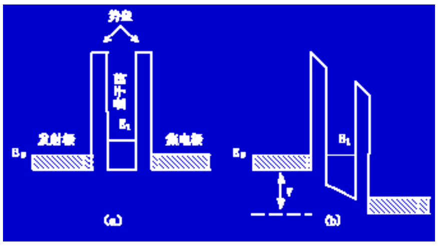


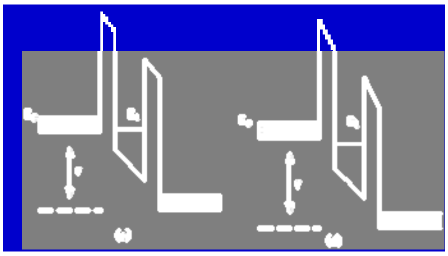


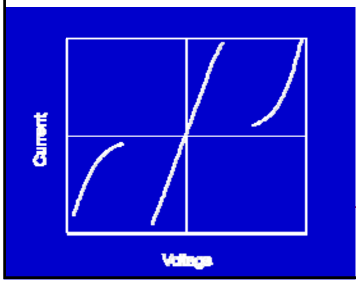
T T

RTD

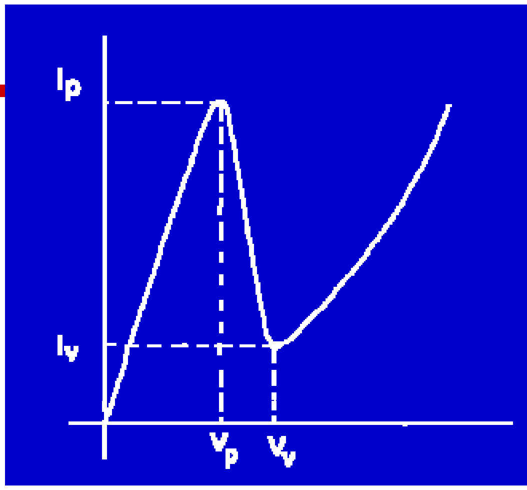
1 RTD







RTD



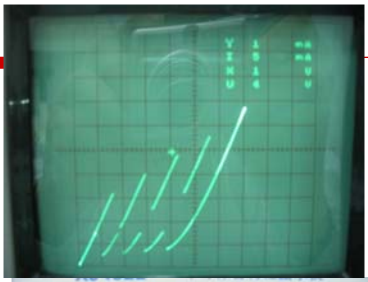
Vp Ip:

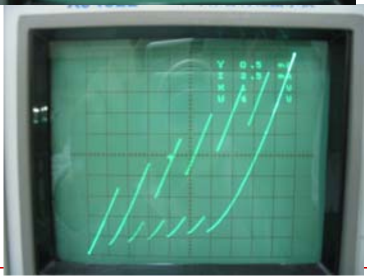
Vv: Iv

PVCR I_p/I_v

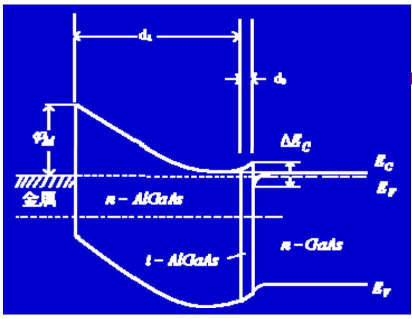
RTD/HEMT Integration

InP based RTD

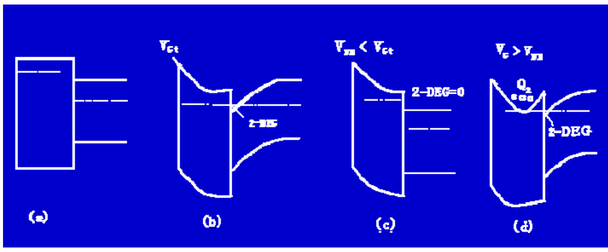




HEMT



V_{GS} 0



(a)

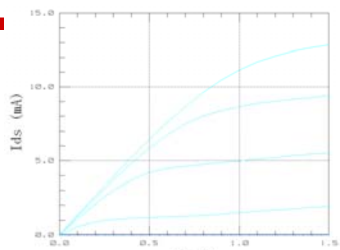
b) V_{Gt}

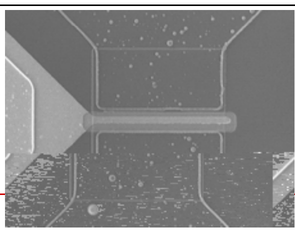
c V_{FB}

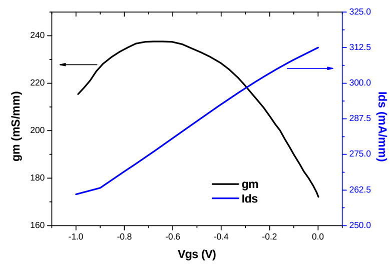
d

HEMT g_{mmax}: 237 mS/mm

$In_{0.53}Ga_{0.47}As$ 20 nm	1e19 cm^{-3}
$In_{0.52}Al_{0.48}As$	20 nm
Si 3e12 cm^{-2}	N/A
$In_{0.52}Al_{0.48}As$	3 nm
$In_{0.53}Ga_{0.47}As$	15 nm
$In_{0.52}Al_{0.48}As$	250nm
InP	200um







[redacted]

HEMT and MMIC Process

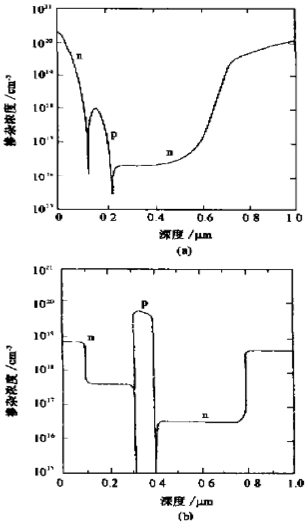
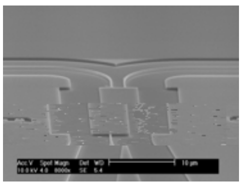
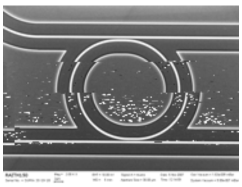
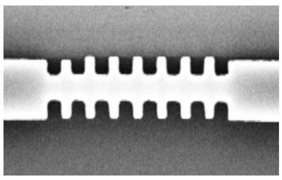


图 4
(a) Si 同质结双极晶体管掺杂分布； (b) AlGaAs/GaAs 异质结双极晶体管的掺杂分布

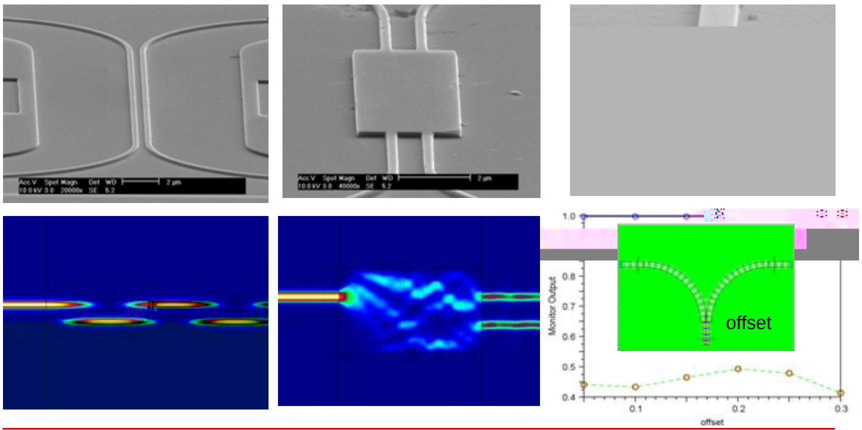
ΔEg = 0　HBT　ΔEg

HBT

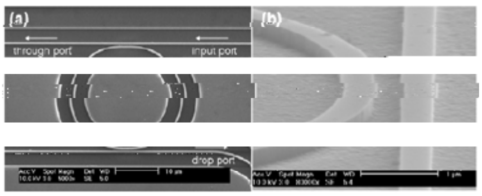
HBT

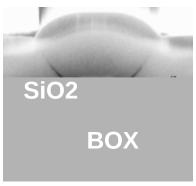




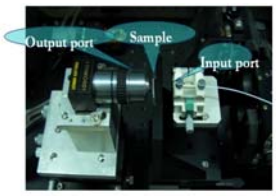
DC MMI



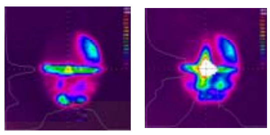
SOI

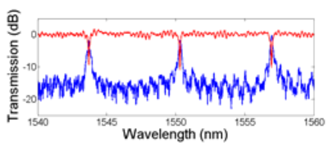






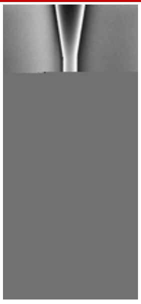
Q 21,200 0.77dB/mm

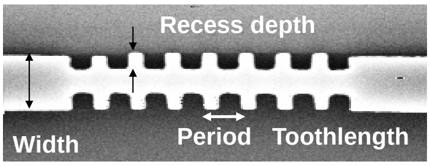


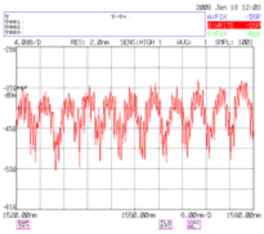


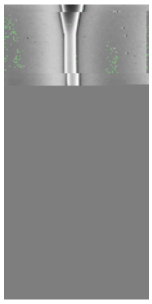
SOI

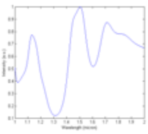
FP



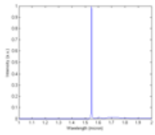




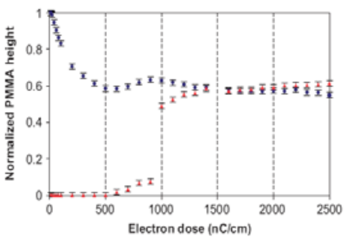




Bragg Reflector

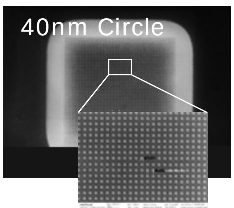


Fabry-perot cavity



➢

➢



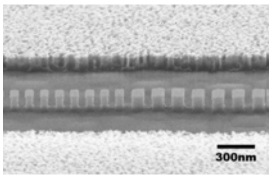
100 × 300 pC/cm

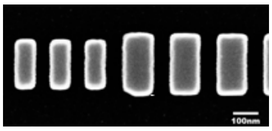
PMMA

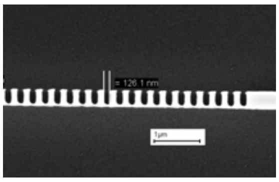
PMMA

PMMA

Bragg



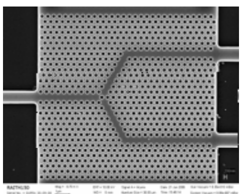


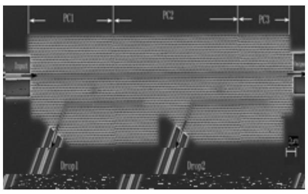


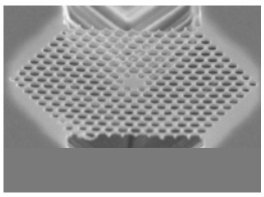
80 × 190 nm²

110 × 240 nm²

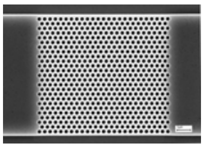
230nm 400nm

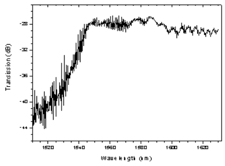




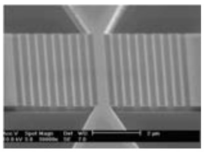


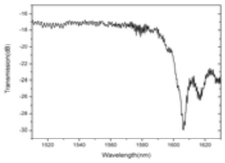
□ 光子晶体结构使光介质的折射率在空间上以光波长量级周期性地变化，使某一能量范围的光子不能通过，形成光子禁带。如果改变空间上某一区域的折射率变化周期，存在于该区域的光子将被局域。由于该区域的折射率周期被破坏，称该区域为缺陷。



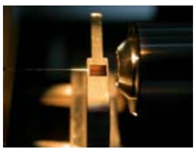


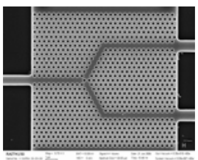
设计: 。
对应的带隙范围为 。
测试: 波长应为光子带隙的长波长带边。与设计值 基本相符。

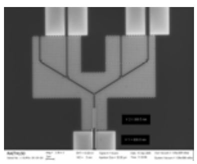


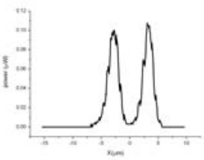


设计: a=410nm, r=131nm 。波导的透射带范围是 。
测试: 波长是透射带的长波长带边，这与模拟结果（ ）相符









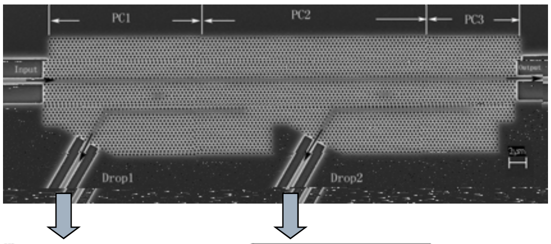
□ 原理：在二维光子晶体中，引入一个线缺陷，沿着线缺陷区域的折射率变化周期发生改变，这一能量范围的光子将被允许在该区域局域传播。利用光子晶体的带隙限制效应，形成光子晶体波导。

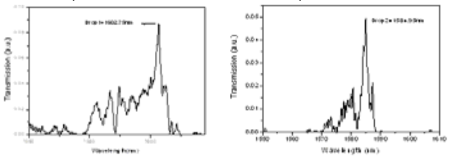
□ 2 4

× 的分束器的参数
周期 = ，
孔半径 = ，
中心小孔的半径 =

× 的分束器的参数
周期 = ，
孔的半径 = ，
缺陷小孔的半径为 =

□ 如果两条线缺陷靠得很近，光波互相耦合，成为光子晶体耦合器;





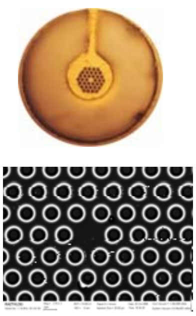
■

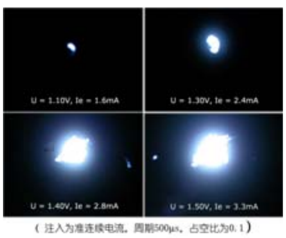
■ Drop2

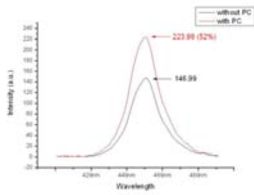
Drop1

LED

□ 引入一个点缺陷或环缺陷，便可构成谐振腔，在有源半导体中光波可获得增益，成为光子晶体微腔激光器或**LED**;

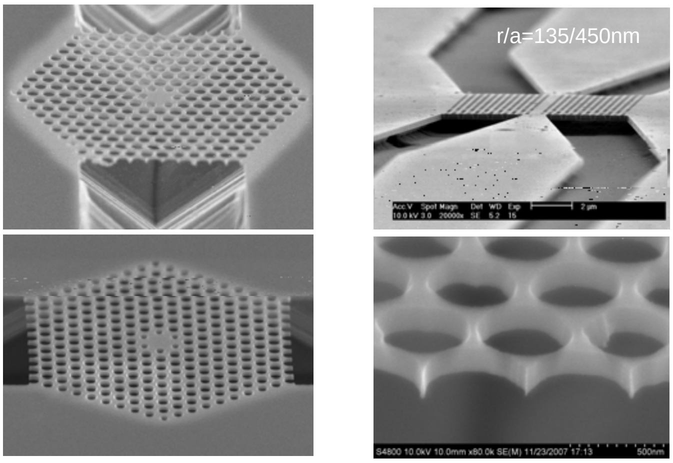


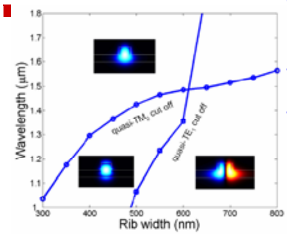




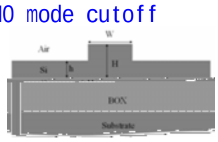
GaAs VCSEL LED

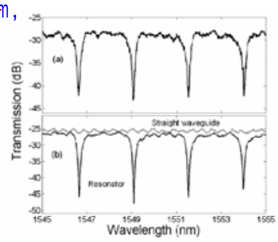
SOI

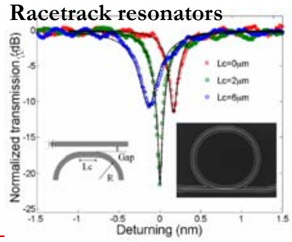


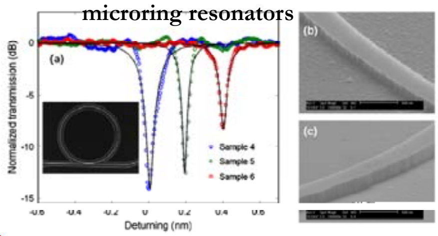


W=440nm/350nm,H=340nm,
h=170nm:
TE0 mode guided,
TM0 mode cutoff









Q.Z Huang et al. Optics Communications 282 p22–26 (2009).

1

2

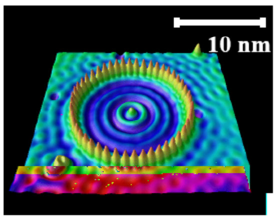
3

4

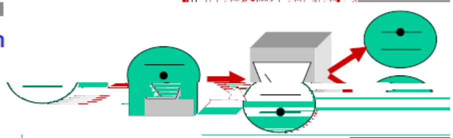
Quantum Information Science

- **Quantum Mechanics**
  - **. . . is weird!**
    - Particles act like waves
    - Particles tunnel through "impenetrable" barriers
    - Particles can be in two states at once
    - Entangled particles are
- **Quantum Info. Science**
  - **Quantum computers**
    - Solve problems classical
  - **Quantum communication**
    - Security guaranteed by

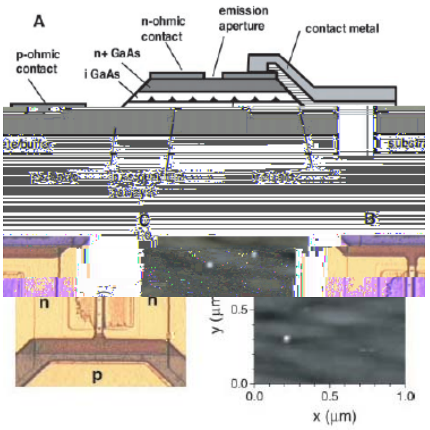
Electron Waves

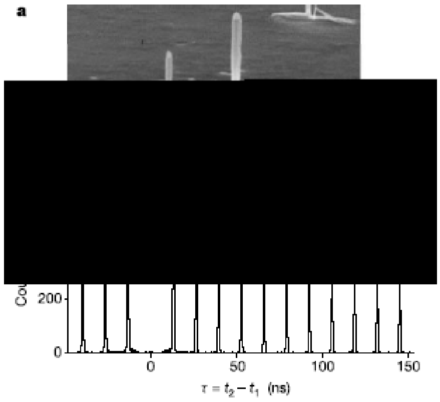


Superposition and



Single Photon Emission Using Single InAs Quantum Dot

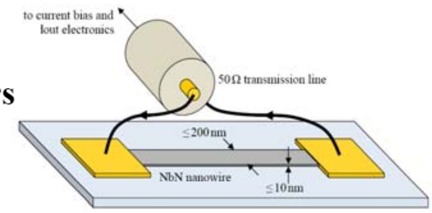


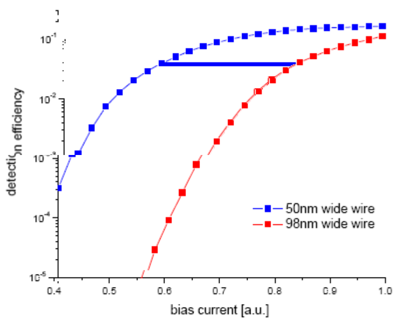


Z. Yuan *et al*., *Science* 295, (2002) 102

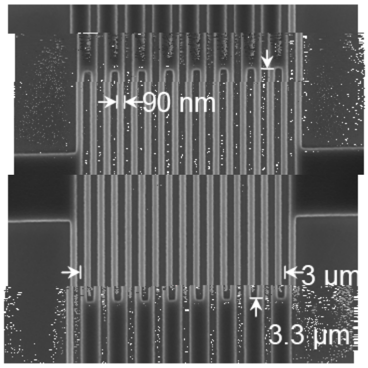
C. Santori *et al*.(Stanford), *Nature* 419, (2002) 594

Multi-element Superconducting Nanowire Single Photon Detectors



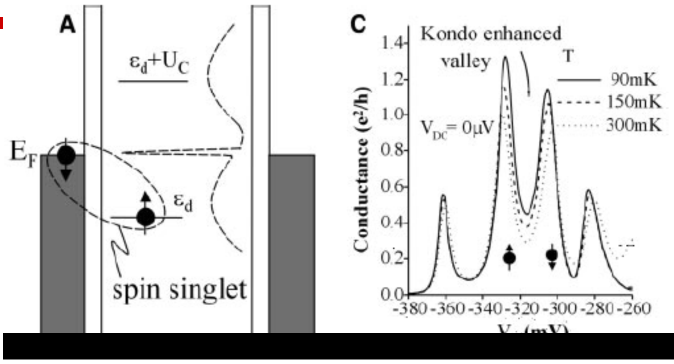


(a)



(b)

-

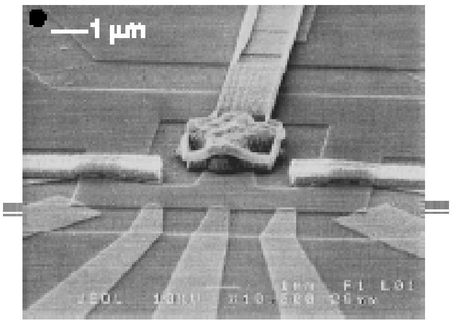


Phase Evolution in a Kondo-Correlated System

Yang Ji, M. Heiblum,* D. Sprinzak, D. Mahalu, Hadas Shtrikman

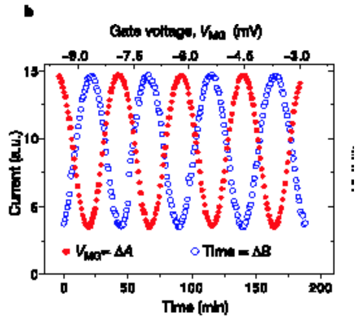
Science, 290, 779(2000)
100

Mach-Zehnder



Mach-Zehnder

Visibility 60%



An electronic Mach–Zehnder interferometer

Yang Ji, Yunchul Chung, D. Sprinzak, M. Heiblum, D. Mahalu & Hadas Shtrikman

Nature, 422, 415(2003)
SCI 60

Physical Implementations for Quantum Computing

Metal Rings as Quantum Bits

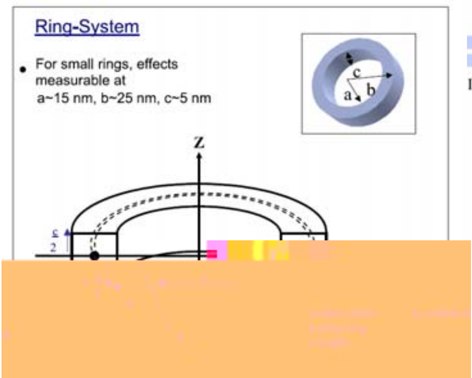
ESSDERC 2002

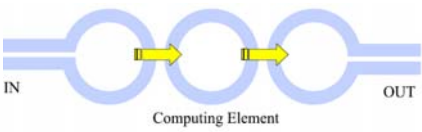
For n q-bits , the register state ψ can be described by a linear combination of 2^n q-bit basis vectors

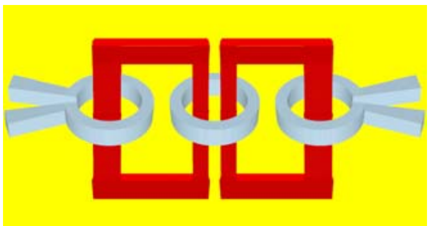
$$|\psi\rangle = \sum_{i=0}^{2^n-1} \alpha_i$$

For the application of Shor's algorithm [1], a quantum computer would be exponentially faster than a classical one.

Metal Rings as Quantum Bits

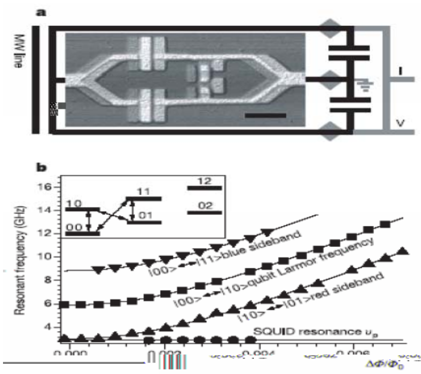


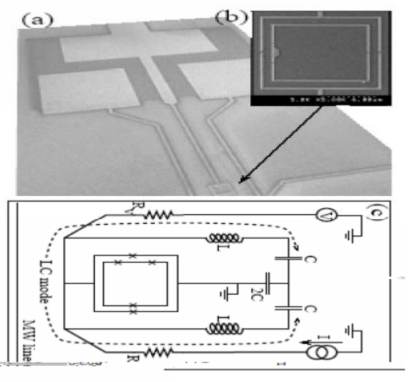




Scalable superconducting qubitcircuits using dressed states

Coupling between an LC circuit and a flux qubit

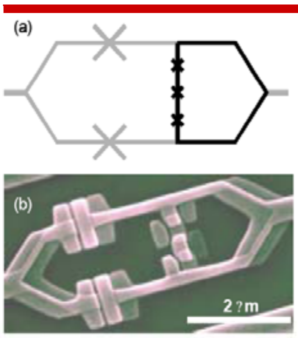


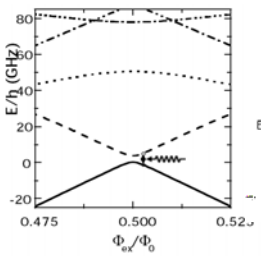


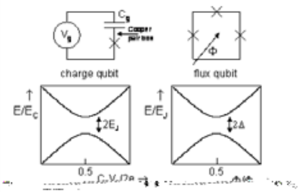
2720060(2006) Delft, Nature, 2004 NTT, PRL 96, 1:

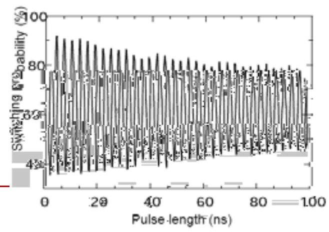
Coherent control of a Josephson-Junction Flux Qubit

Y. Nakamura_1,2, I. Chiorescu3, C.J.P.M. Harmans3 and J.E. Mooij3





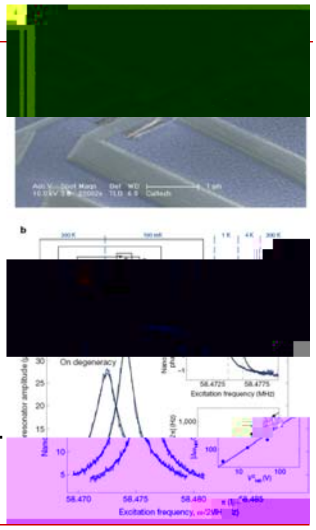




Three-junction flux qubit. (a) Schematics. The gray part is for the readout. (b) Scanning-electron micrograph. The larger loop with two big junctions is a SQUID for readout.

20100401

Nanomechanical measurements of a superconducting qubit



Device and measurement circuit description, and driven frequency response of the nanoresonator.

c, Thenanoresonator's amplitude (main panel) and phase (upper inset) versus excitation frequency, v, for nCPB biased on and off a charge degeneracy and EJ/h<10 GHz. The solid black lines each denote a fit to a harmonic oscillator response. Lower inset: magnitude of the nanoresonator frequency shift, |DvNR/2p| (black circles) as a function ofV2 NRfor EJ/h<11–12 GHzandVCPB biased at a charge degeneracy. The solid blue line is a fit to |DvNR/ 2p| 5AV2 NR, where A is a proportionality constant.

1

2

3

4

Thank you for your attention

20100401 - 105

20100401 - 106

-