Integrated Photonic Devices

http://ioe.eei.eng.osaka-u.ac.jp/

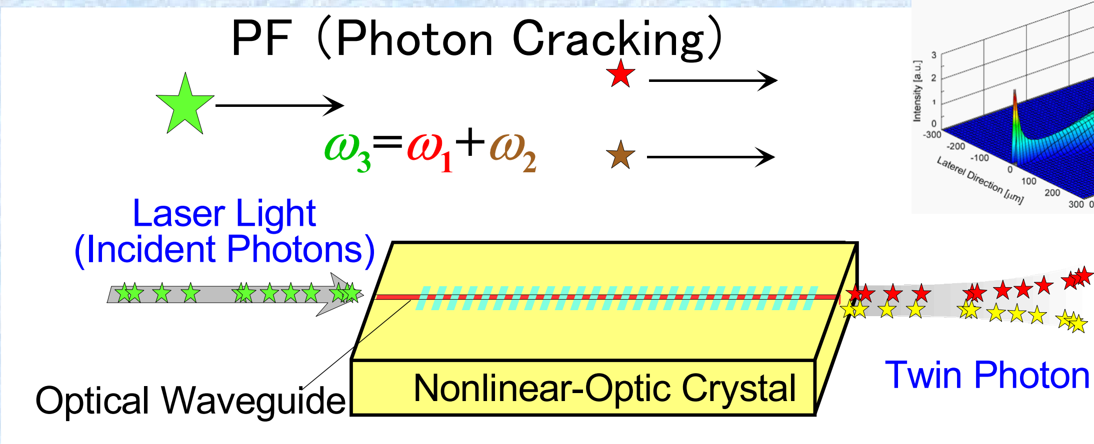
Advanced Integrated Photonic Devices

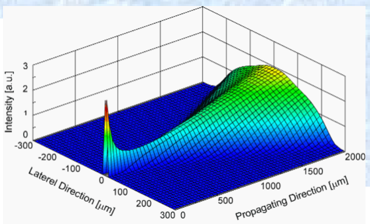
- IPD for Optical Network
- IPD for Ultrafast Signal Processing
- Quantum Structure Semiconductor Lasers
- Integrated Photonic Sensors
- Integrated Quantum Photonic Devices

Electron Beam Writing System for Photonics

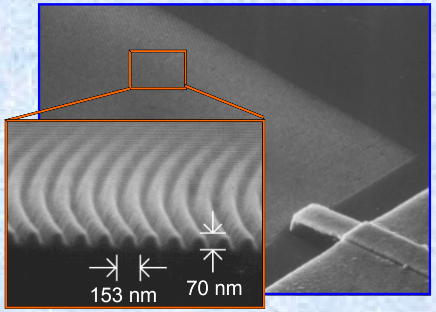
Design Theory Simulation Fabrication Technology

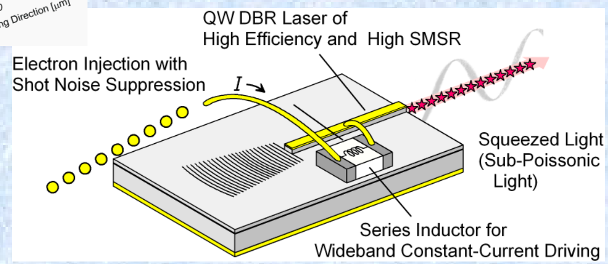
Device Implementation・Experimental Demonstration





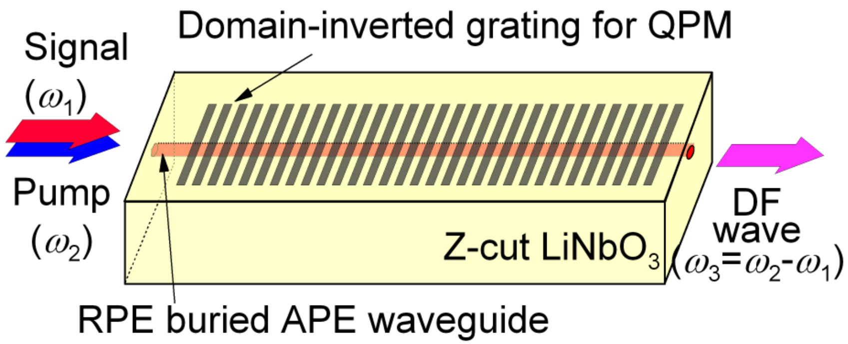
An Example of Quantum Photonic Devices

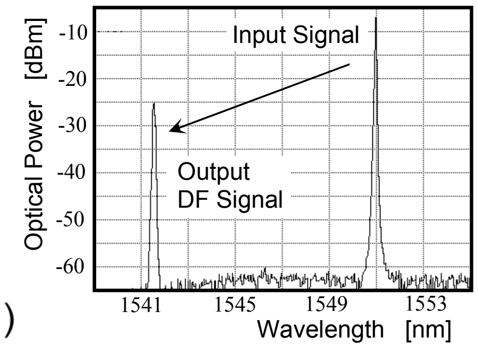


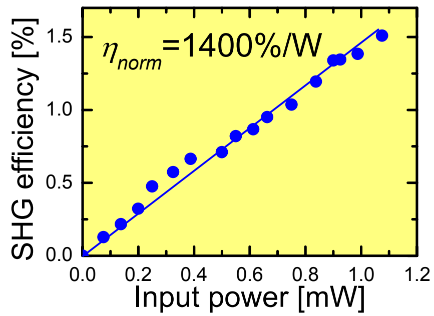


Integrated QW Semiconductor Laser

Waveguide Nonlinear-Optic Devices

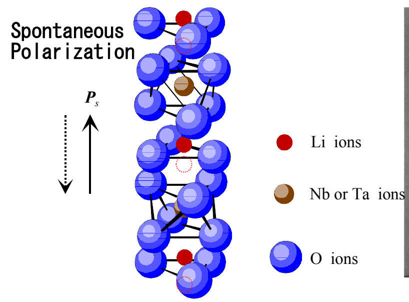


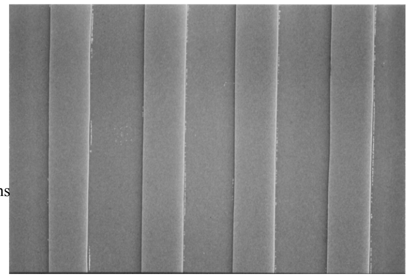




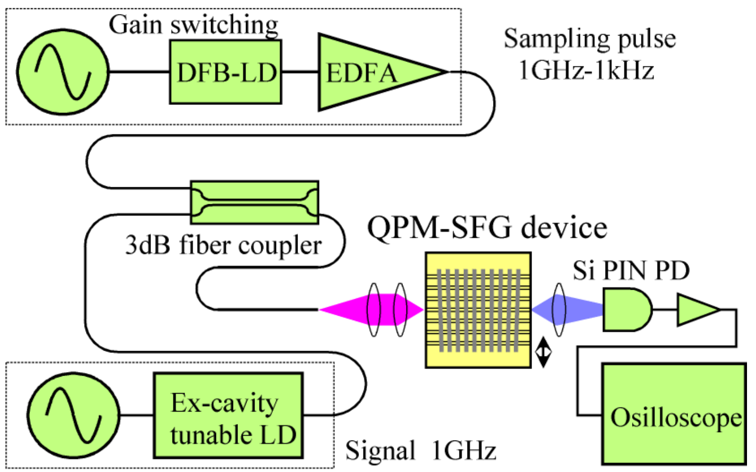
Top Data Efficiency

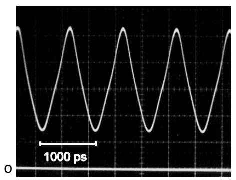
Wavelength Converters for Photonic Network





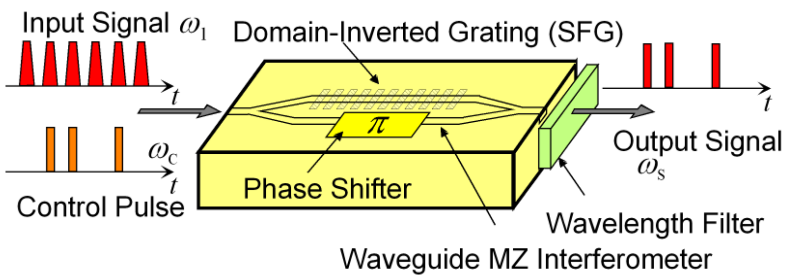
Domain Inverted Grating for QPM





43%/W
Highest Efficiency

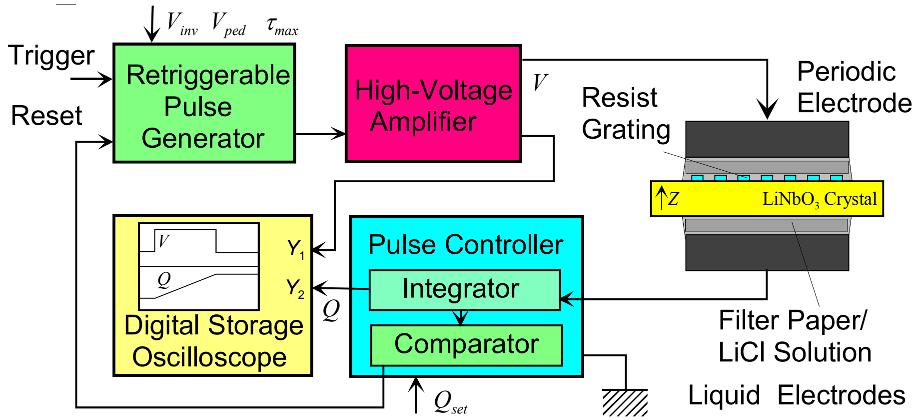
Optical Sampling Device

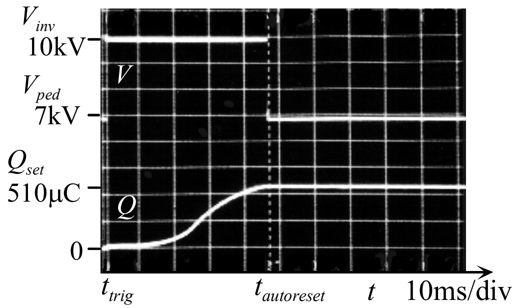


Ultrafast Optical Gate Switch

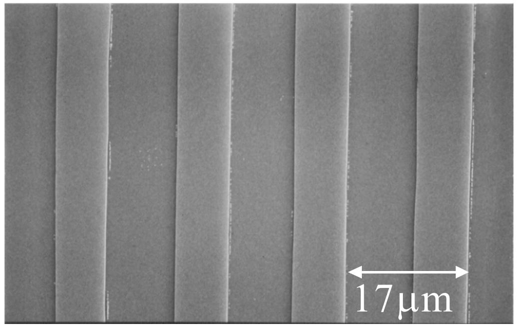
Formation of Domain-Inverted Grating for QPM

Voltage Pulse Application using Liquid Electrodes



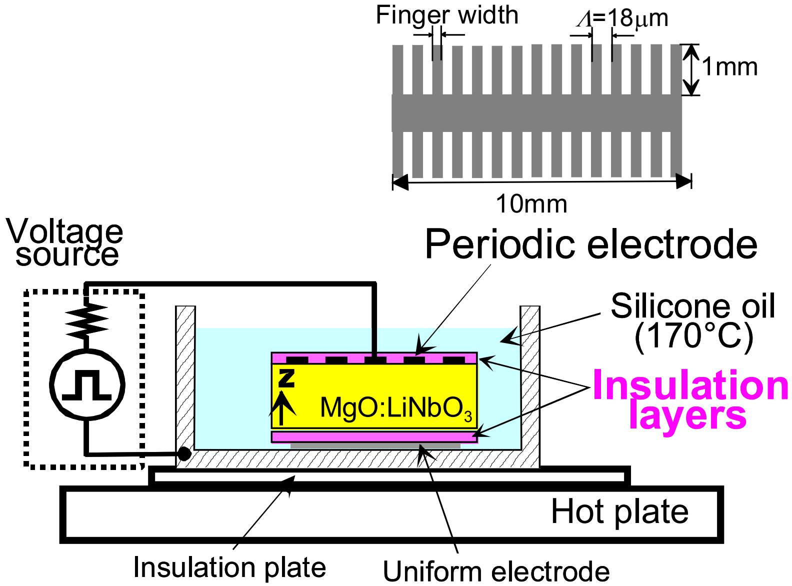


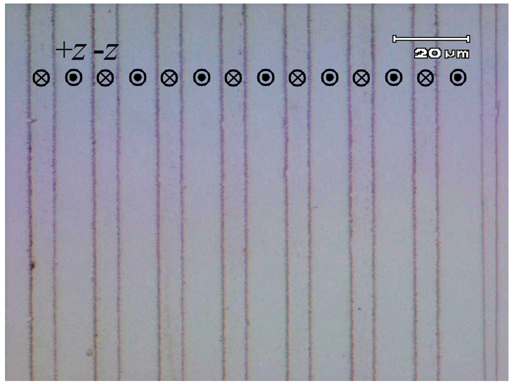
Voltage /Charge Traces



SEM Microphotograph of Domain-Inverted Grating

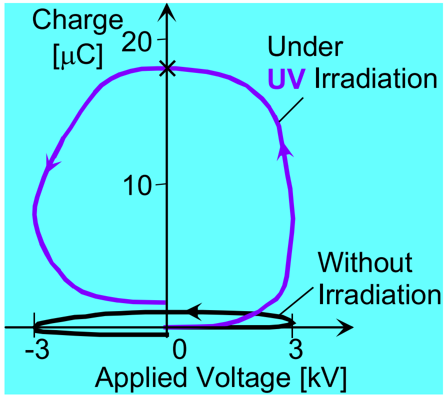
Voltage Pulse Application using Metal Electrodes





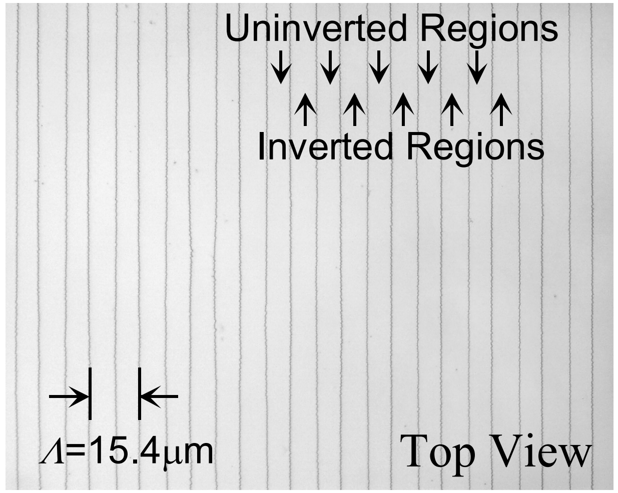
N.Horikawa, T. Tsubouchi, M.Fujimura and T.Suhara, Jpn. J. Appl. Phys., 46, 5178, 2007.

QPM Grating Formation in $MgO:LiNbO_3$ Crystal



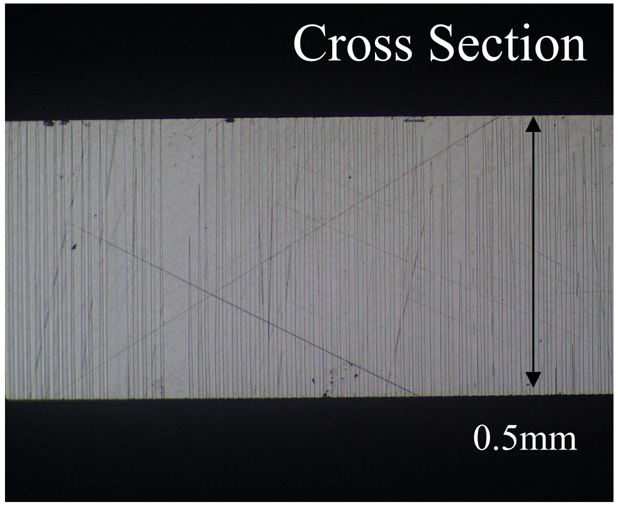
$MgO:LiNbO_3$
PR damage resistant

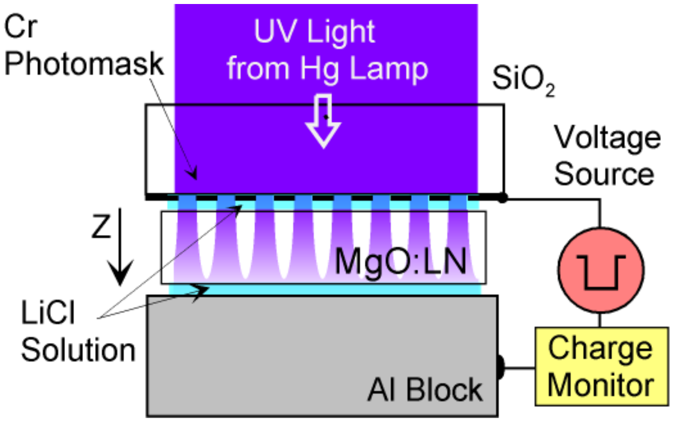
UV Irradiation
Reduces
Eff. Coercive Field

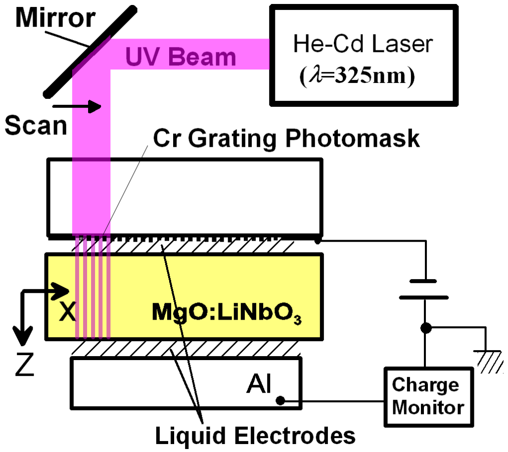


Ferroelectric Hysteresis Loop

Room Temperature Resistless Process





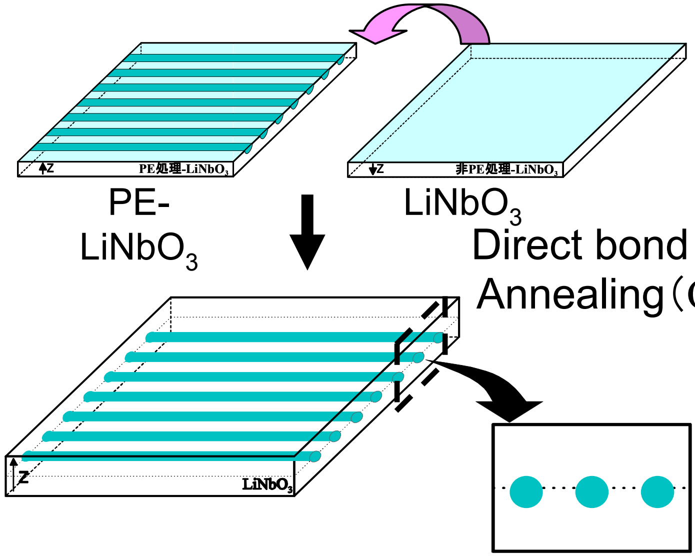


Formation of QPM Grating

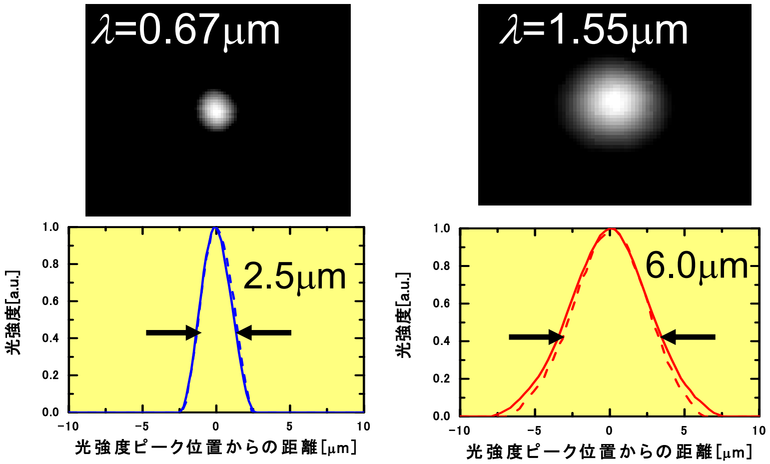
M.Fujimura, T.Sohmura and T.Suhara EL. 39, 719, 2003

Fabrication of WG of strong confinement

Buried APE WG fabrication by direct bonding

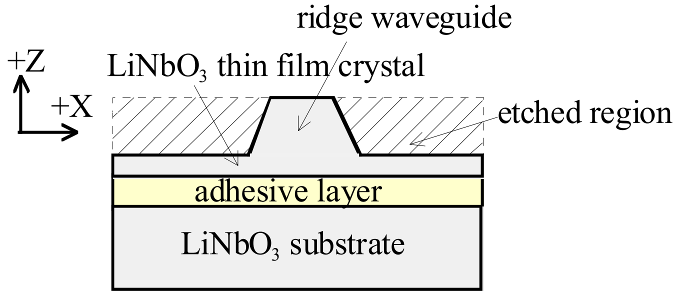


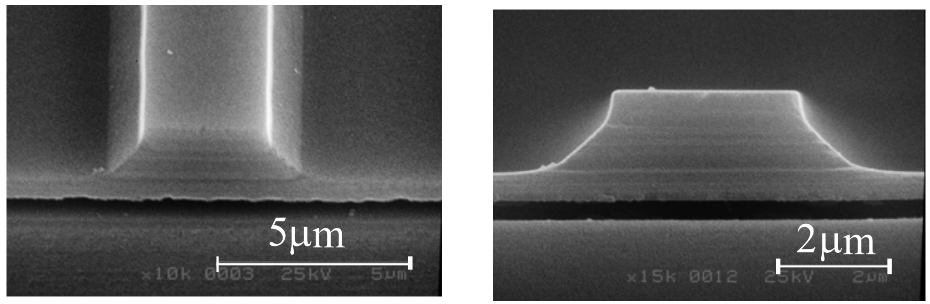
Direct bond（220℃,3h）
Annealing（O_2 370℃,4h）

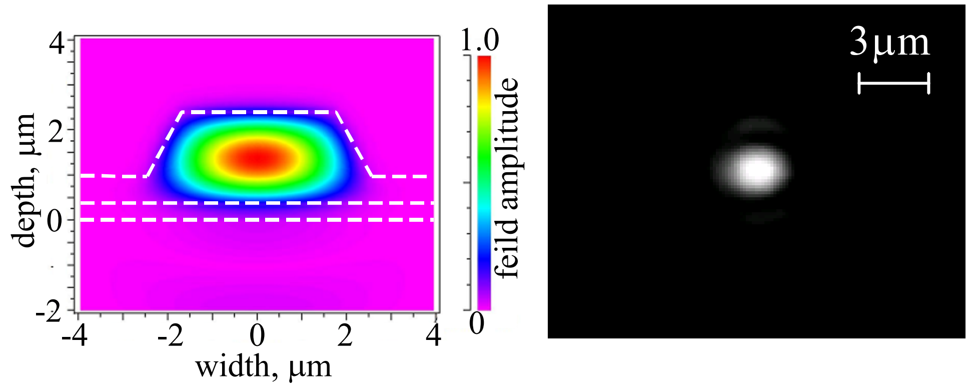


M.Fujimura et al. EL **44**, 856 2008

Ridge WG fabrication by PE accelerated chemical etching







T.Takaoka et al. EL **45**, 940 2009

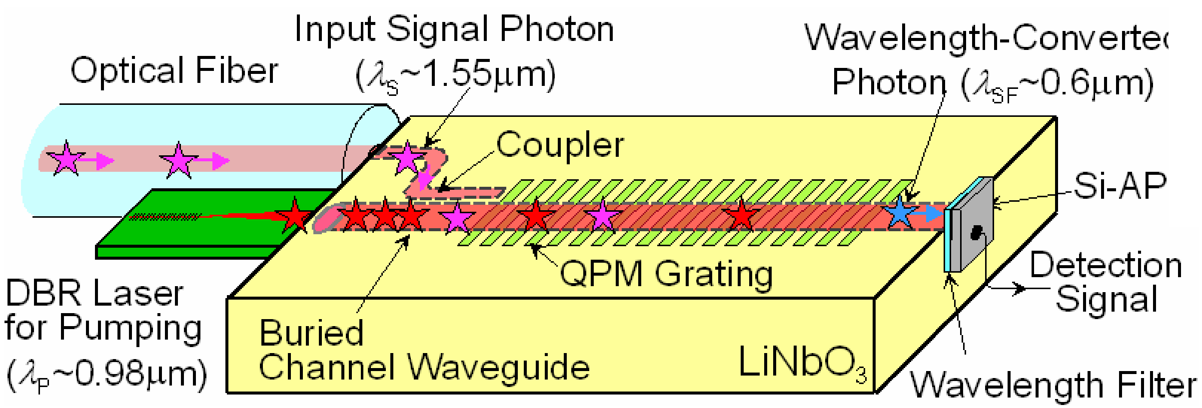
QPM WG SFG upconversion device for single photon detection

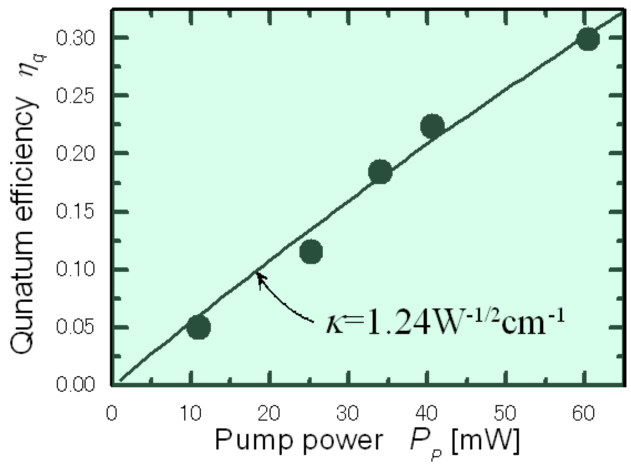
QIT　Photon transmission through fiber network

Telecom（1.3, 1.5μm)band　Single photon detector

InGaAs-APD involve drawbaks

SFG upconversion to visible and detection by Si-APD





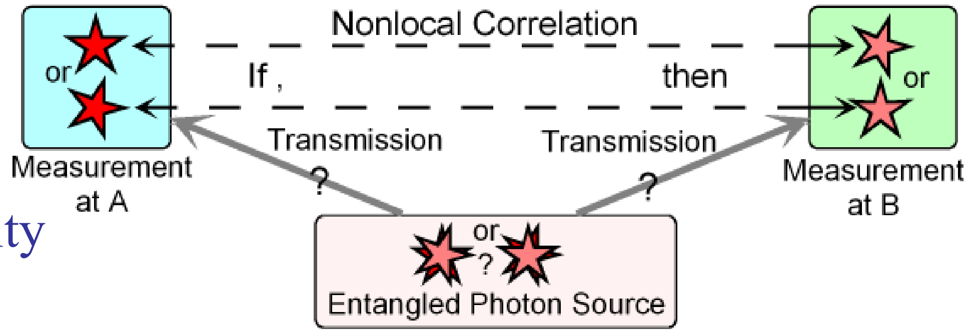
η~30%　@P_p=60mW

M.Fujimura, et al. JJAP **46**, 9A, 5868, 2007

WG QPM Entangled Twin Photon Generation Devoces

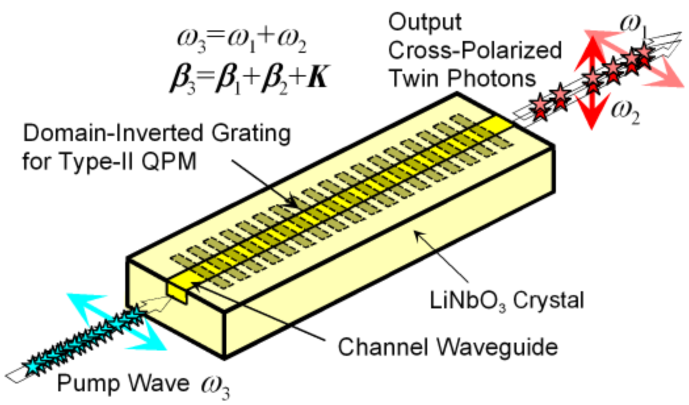
QPM Waveguide NLO Devices for Quantum Information Processing
Q-Cryptography, Q-Teleportation, Q-Interface, …

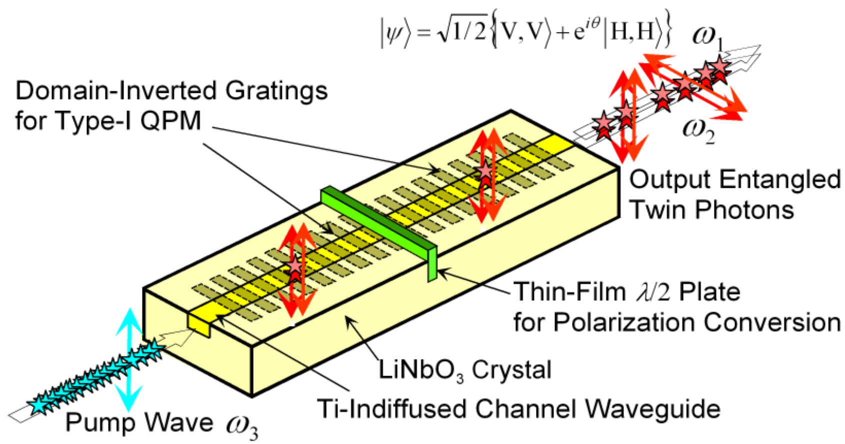
Quantum Entangled Twin Photons



high efficiency, wavelength flexibility
Integration compatibility

Key Devise for QIT





T.Suhara et al. IEEE PTL **19**, p.1093,2007.   J.Kawashima et al., IEEE PTL., **21,** p.566, 2009.

Quantum theory analysis of TPG

Quantum coupled mode eq (H.P.)

$$\frac{d}{dz}a_1(z) = i\kappa A_3 a_2^{\dagger}(z)\exp(i2\Delta z)$$

$$\frac{d}{dz}a_2(z) = i\kappa A_3 a_1^{\dagger}(z)\exp(i2\Delta z)$$

$$\langle N_1(L)\rangle = \langle N_2(L)\rangle = \sinh^2 \Gamma L\{\sin\Delta L/\Delta L\}^2$$

$$P_{out1} = \hbar\omega_1 \int \langle N_1(L)\rangle (d\omega_1/2\pi) \text{ in QPM bandwidth}$$

Photon CCR

$$P_c(\tau) \propto \mathrm{rect}\left(2\frac{\delta\omega}{2\pi}\tau\right)$$

Correlation time

$$\tau_c = (\delta\omega/2\pi)^{-1} = |n_1 - n_2| L/c$$

Unitary transformation of state (S.P.)

$$|\phi(L)\rangle = T(L)|0,0\rangle = \exp(-iHL)\,|0,0\rangle$$

$$= \sum_{n=0}^{\infty}\frac{1}{n!}(-iHL)^n|0,0\rangle$$

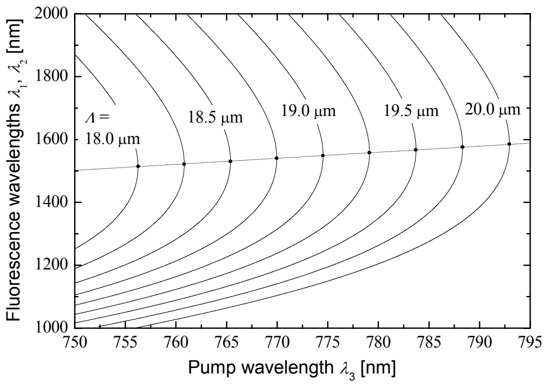
$$H = i\{a_1^{\dagger}(\Gamma e^{i\phi}a_2^{\dagger} - i\Delta a_1) - (\Gamma e^{-i\phi}a_1 + i\Delta a_2^{\dagger})\,a_2\}$$

$$|\phi(L)\rangle = \sum_{n=0}^{\infty}\sqrt{1-|r|^2}\,r^n|n,n\rangle$$

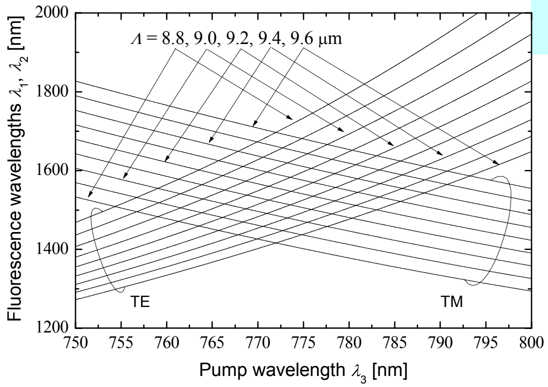
$$r = \frac{e^{i\phi}(\Gamma/\gamma)\sinh\gamma L}{\cosh\gamma L + i(\Delta/\gamma)\sinh\gamma L}$$

$$\langle[\Delta\{N_1(L) - N_2(L)\}]^2\rangle = 0$$

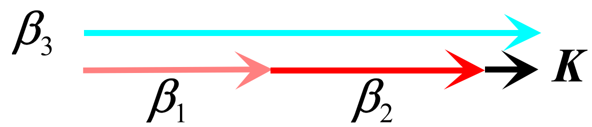
complete correlation



TM→TM+TM Type-I QPM

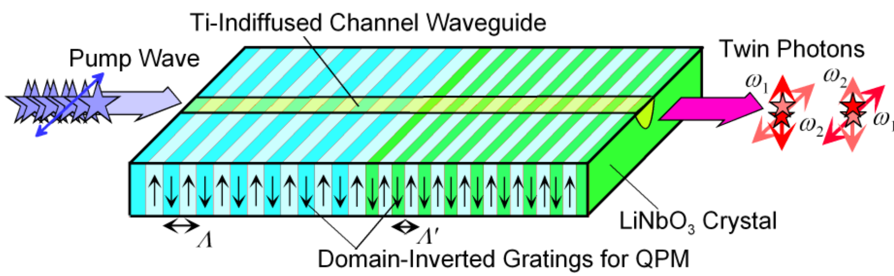


TE→TM+TE Type-II QPM

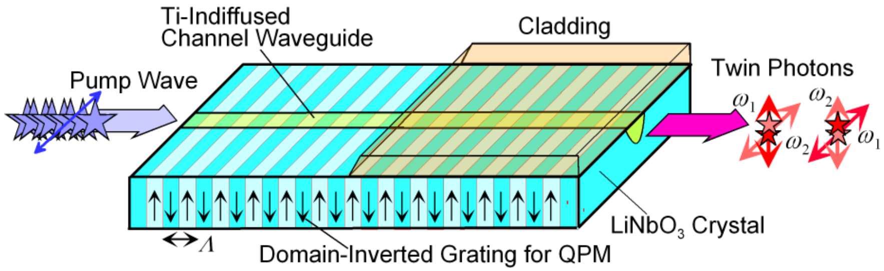


T.Suhara et al. IEEE JQE, **41**, 1203, 2005; **42**, 777, 2006

QPM WG Devices for Generation of Postselection-Free Polarization-Entangled Twin Photons



(a) Biperiod type



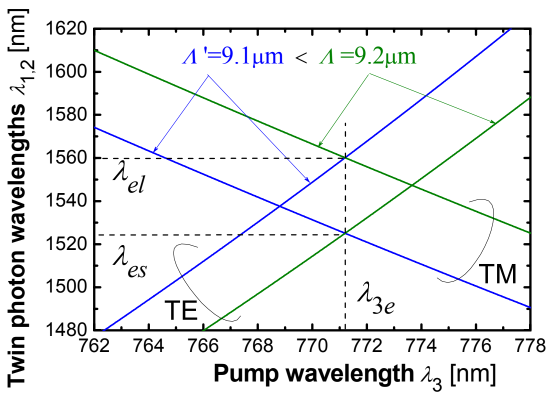
(b) Clad/Unclad type

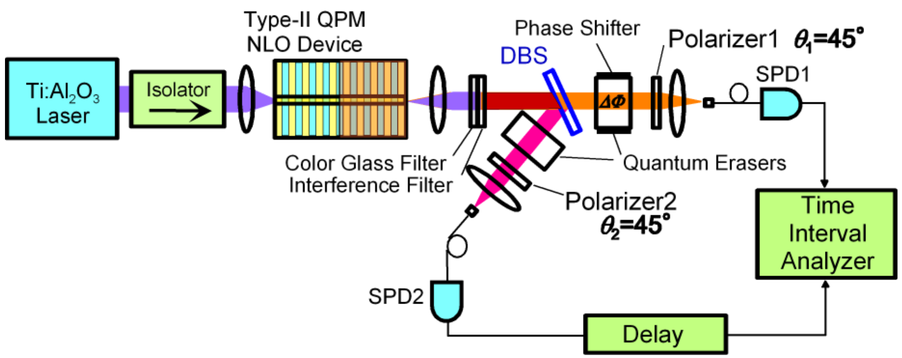
Output state: $|\psi\rangle=\frac{1}{\sqrt{2}}\{|\mathrm{H,V}\rangle+\exp(i\Phi_0)|\mathrm{V,H}\rangle\}$

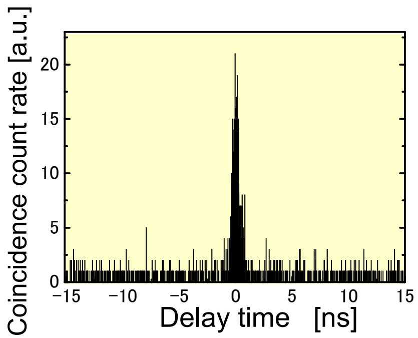
$\lambda_{el}\ \lambda_{es}$ $\lambda_{el}\ \lambda_{es}$

completely separated by DBS

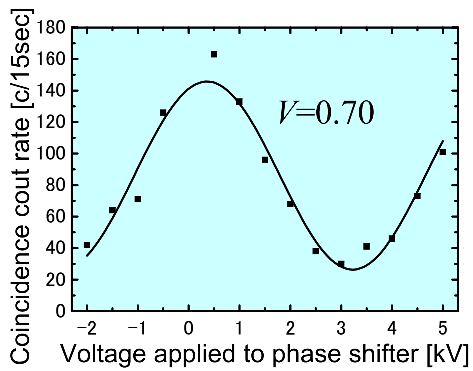
Postselection-free two-λ polarization-entangled twin photons without spurious photon







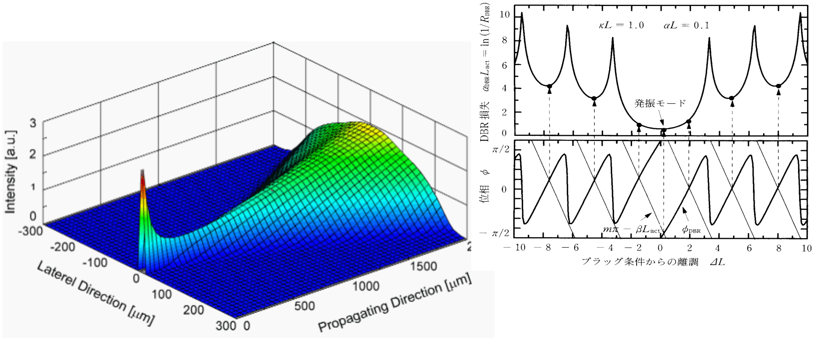
photon correlation



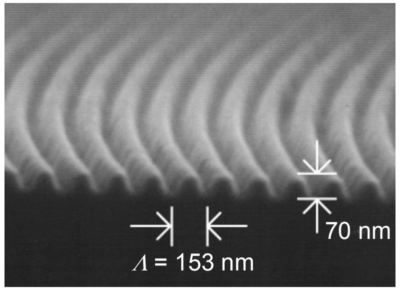
Quantum interference

T.Suhara et al. IEEE PTL **21**, 1096 2009.

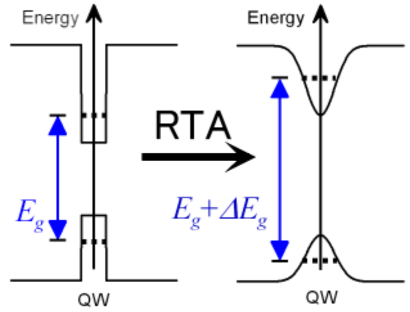
Integrated Semiconductor Lasers



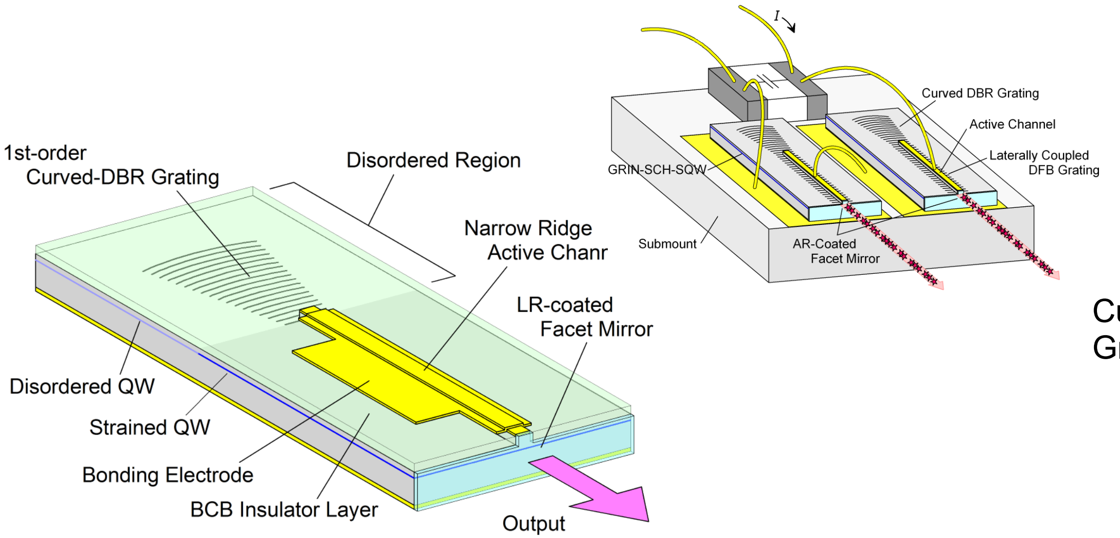
DFB/DBR Laser Simulation



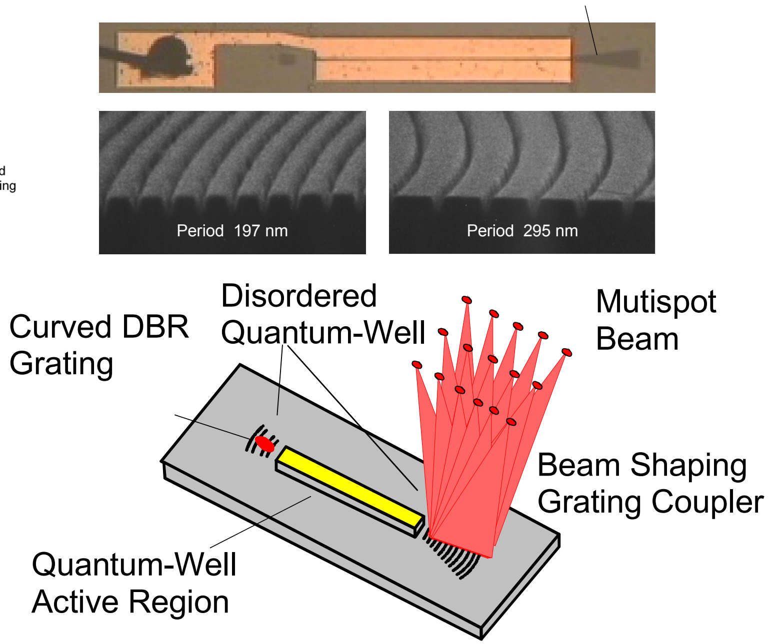
EB Fabrication of Nano Gratings



Selective Disordering of Quantum Well



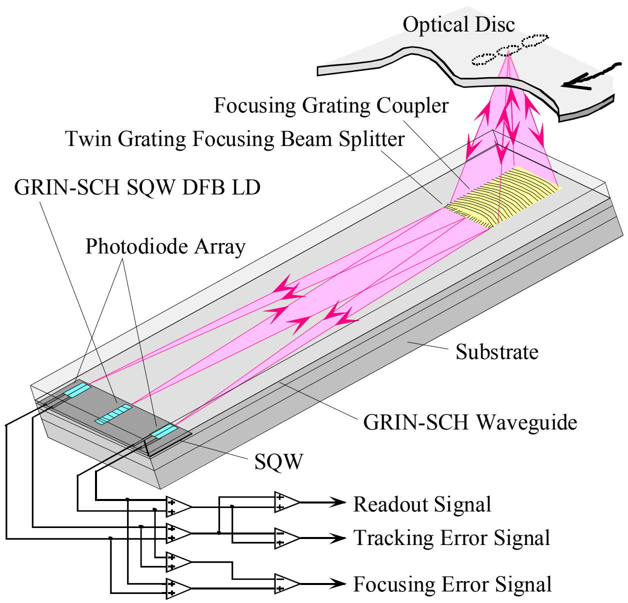
Integrated Semiconductor Lasers for Photonic Network and Quantum-Information



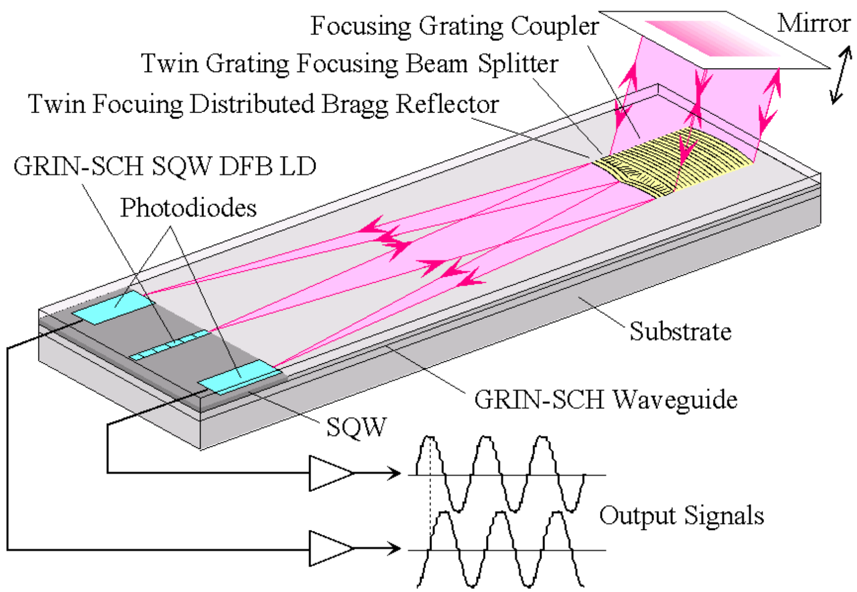
Integrated Semiconductor Lasers for Bio-Sensing

Monolithic Integrated-Optic Sensor Devices

Implementation of IO Sensor Devices by Integration of DFB/DBR Laser, Wavefront Conversion Elements and Photodetectors



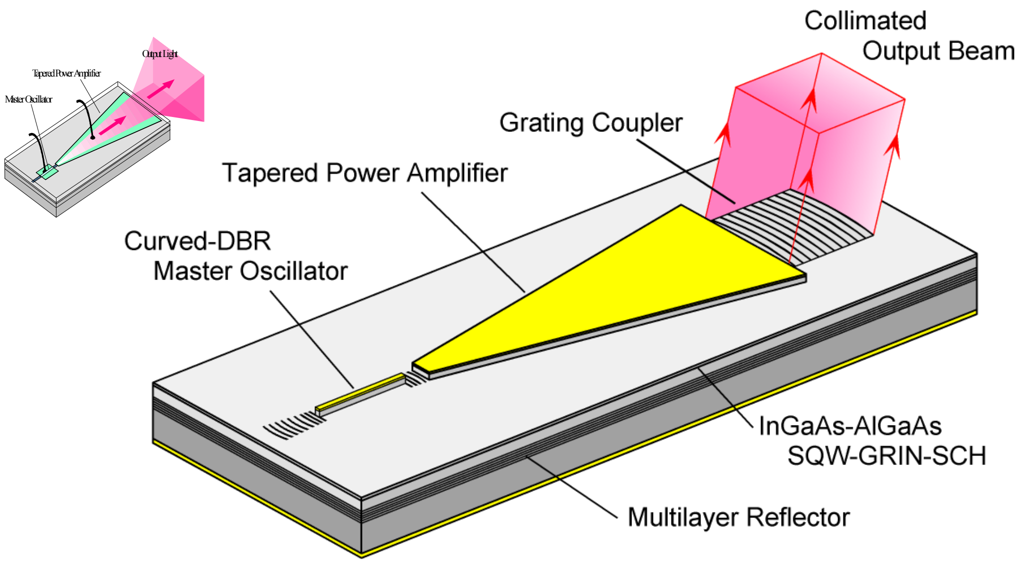
Monolithic Integrated-Optic Disc Pickup Head

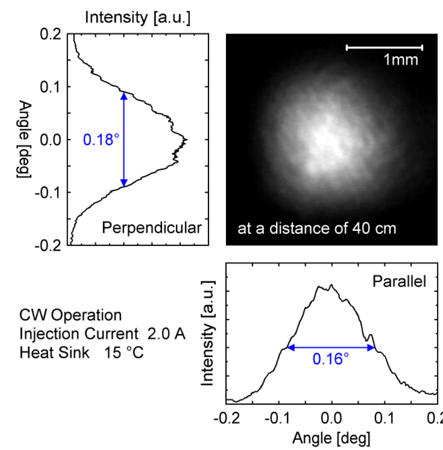


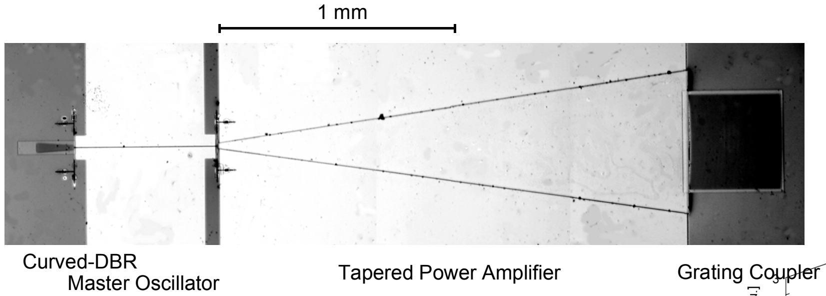
Monolithic Integrated-Optic Interferometer Posision/Displacement Sensor

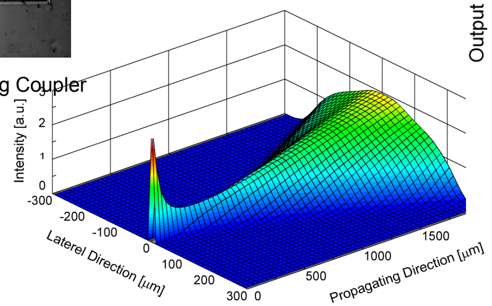
Integrated High-Power High Coherence Semiconductor Lasers

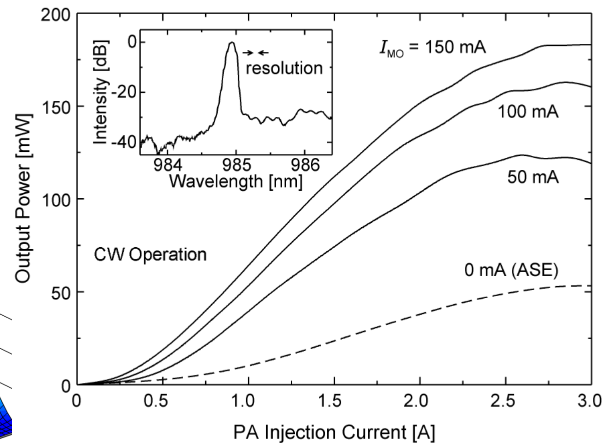
Master Oscillator Power Amplifier with integrated Outcoupler



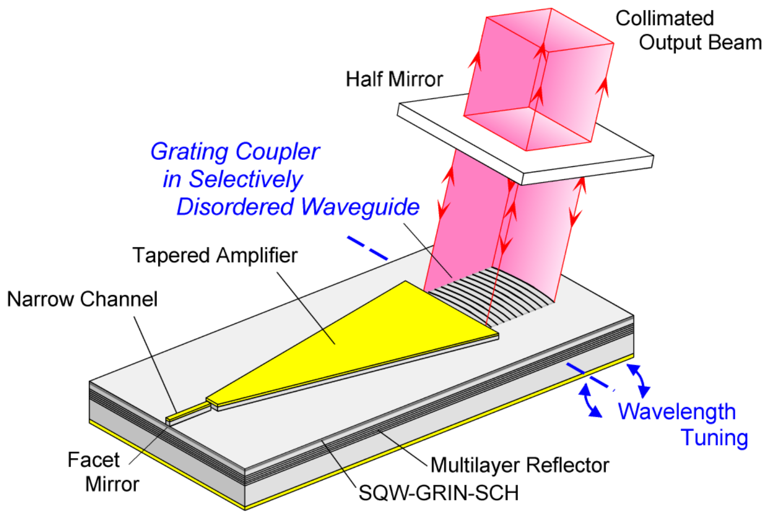


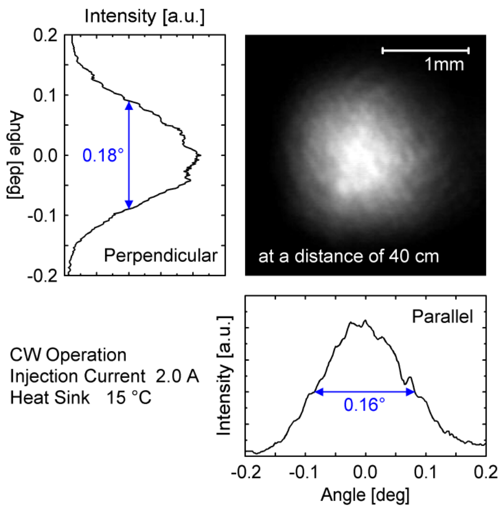


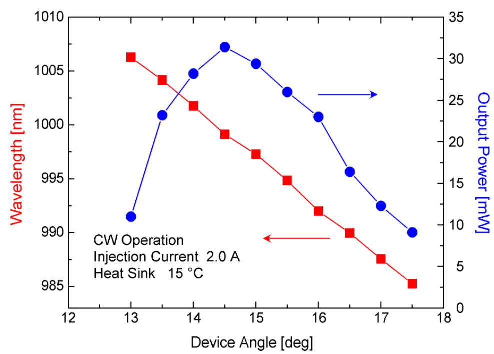


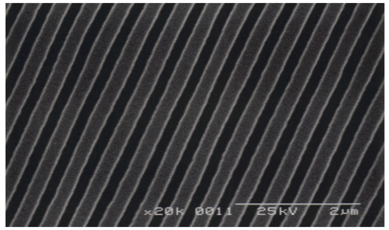


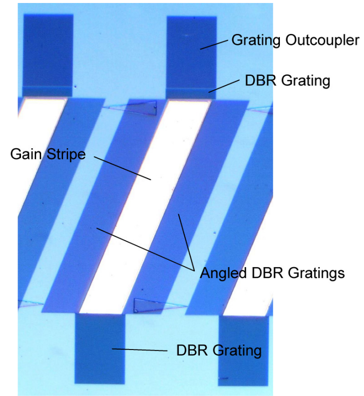
Integrated High-Power High Coherence Semiconductor Lasers

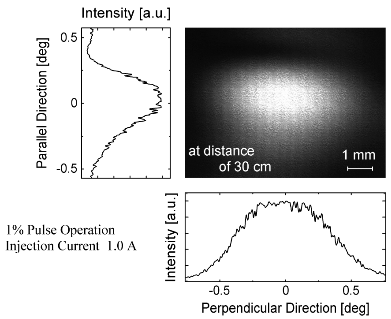


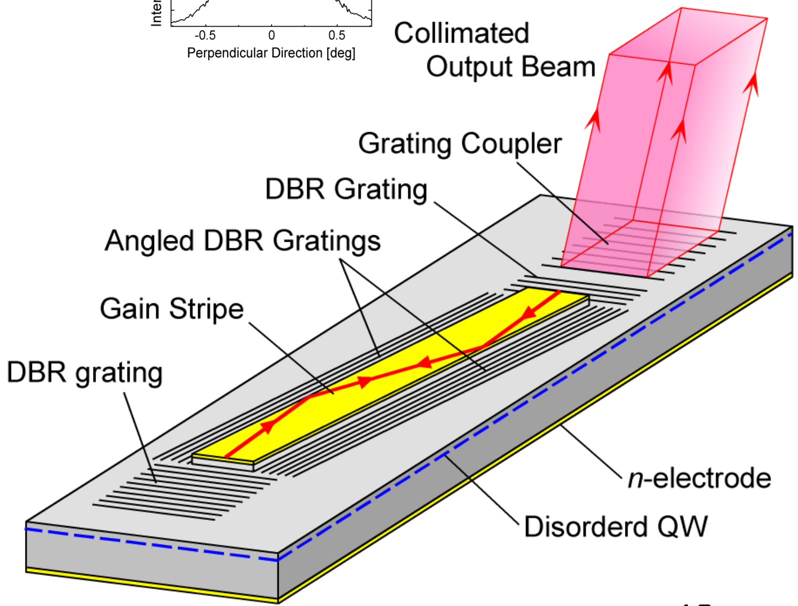








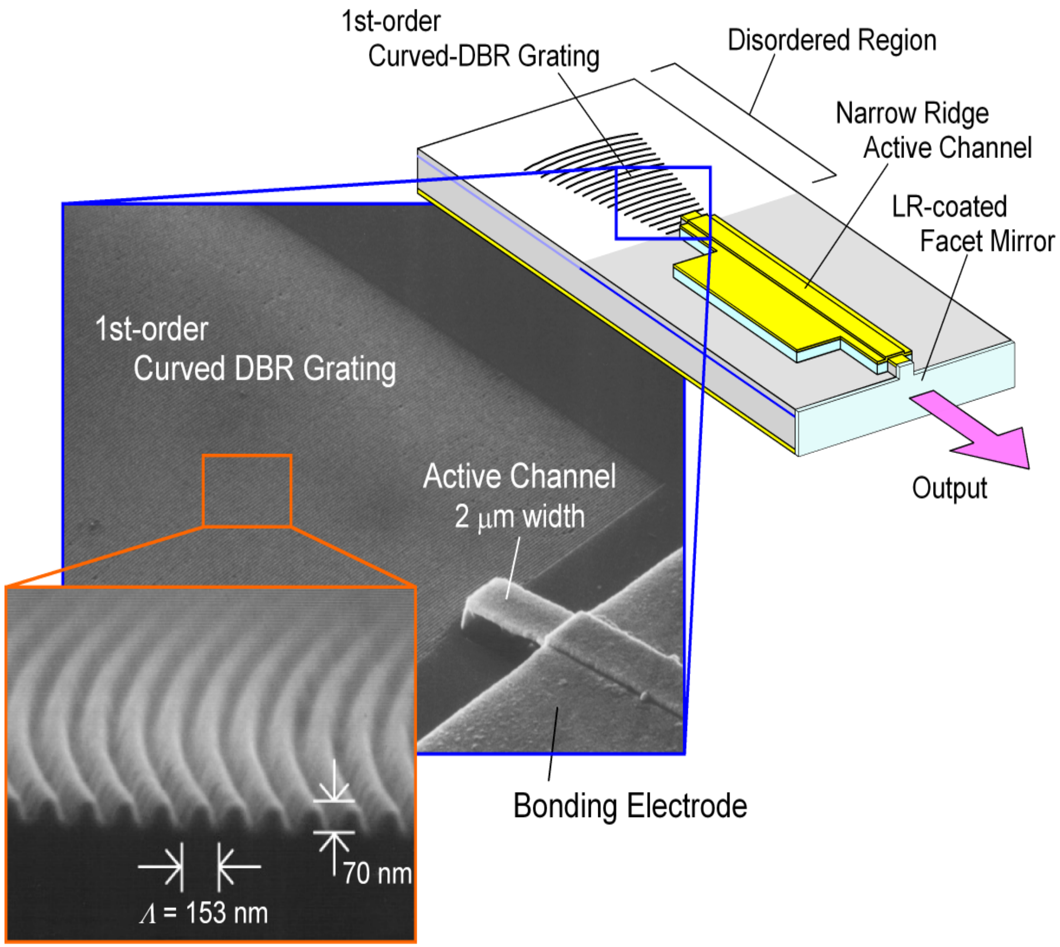


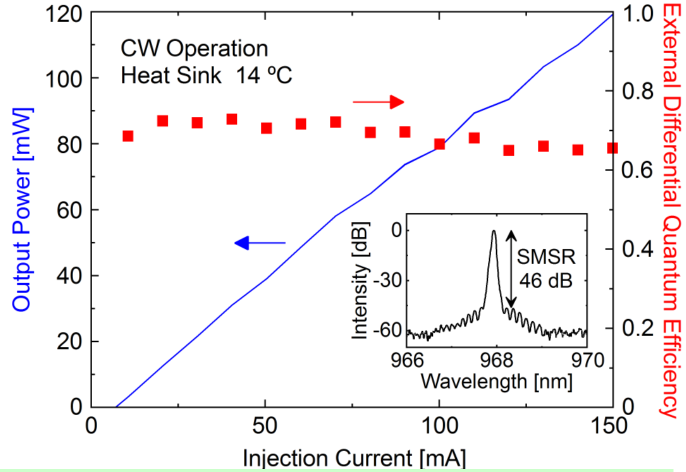


Extended Cavity Tunable Laser

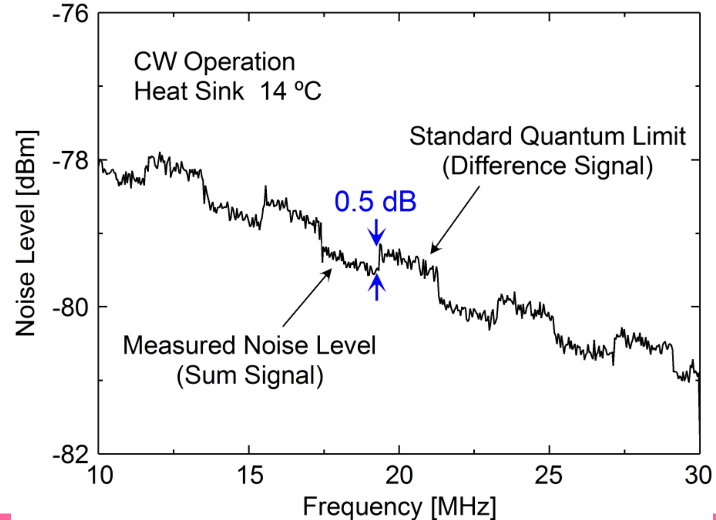
Broad-Area DBR Laser

14InGaAs QW DBR Laser for Squeezed Light Generation





I_{th}=7mA η_d～0.63 Max I/I_{th}=21

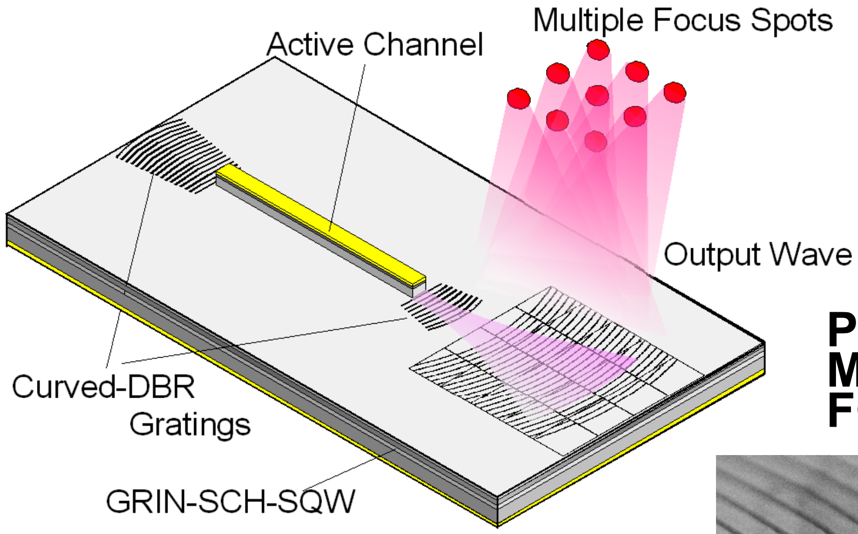


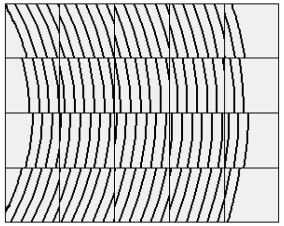
External Quantum Efficiency 74%
Side Mode Suppression 52 dB
Maximum Output Power 250 mW
Accomplished

Generation of Squeezed Light

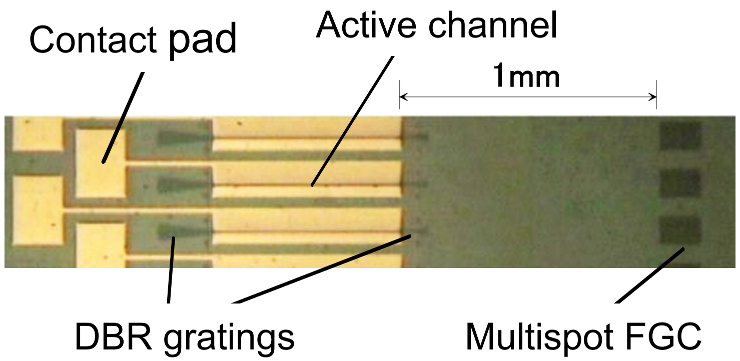
M.Uemukai, et al. IEEE JSTQE, 11, 1143, 2005

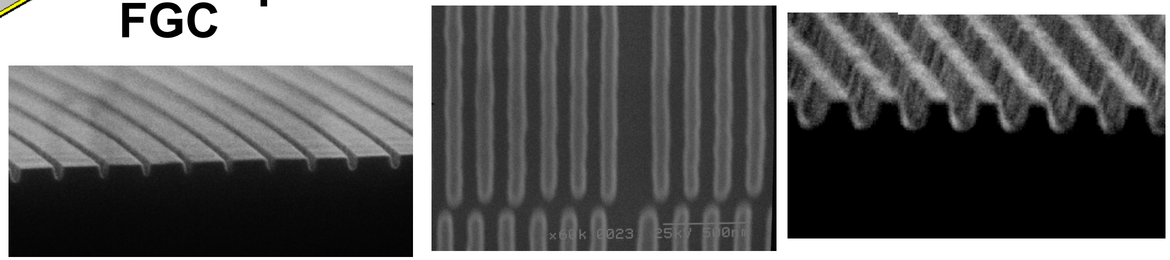
DBR laser with multispot focusing grating coupler



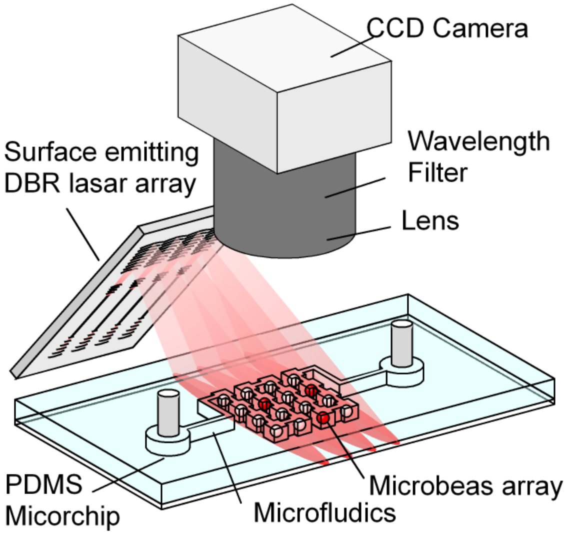


Phase-shifted Multispot FGC

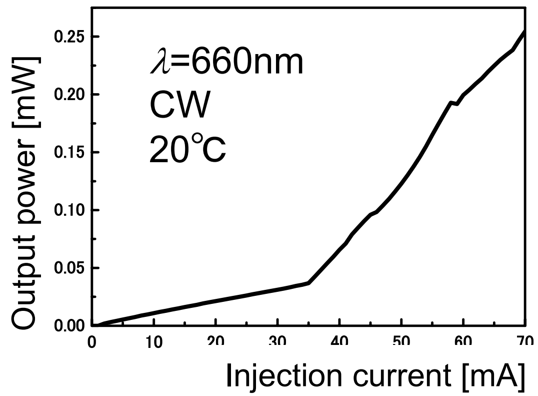


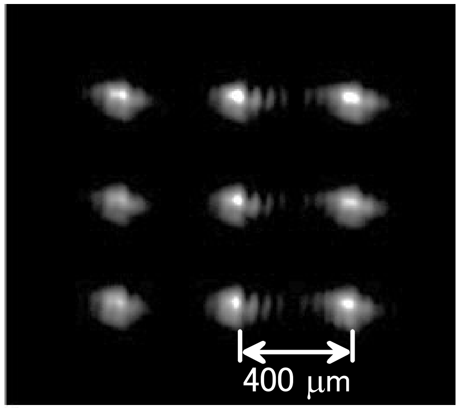


Λ～191nm d～100nm



Application to biosensing





S.Takushima et al. JJAP **48**, 030206, 2009

Integrated twin DBR laser for THz wave generation