Ultrafast Intersubband All-Optical Switch in Wide-gap II-VI Quantum Well toward Lower Switching Energy Operation

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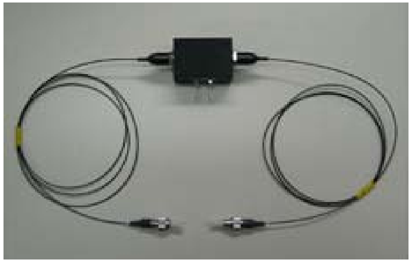
Outline

- Using the intersubband transition all optical switch for high bit rate operation (~160Gbit/s)
- Strong light confinement in waveguide for low switching energy
- Quantum well structure for low saturation energy



II-VI-ISBT all optical switch module

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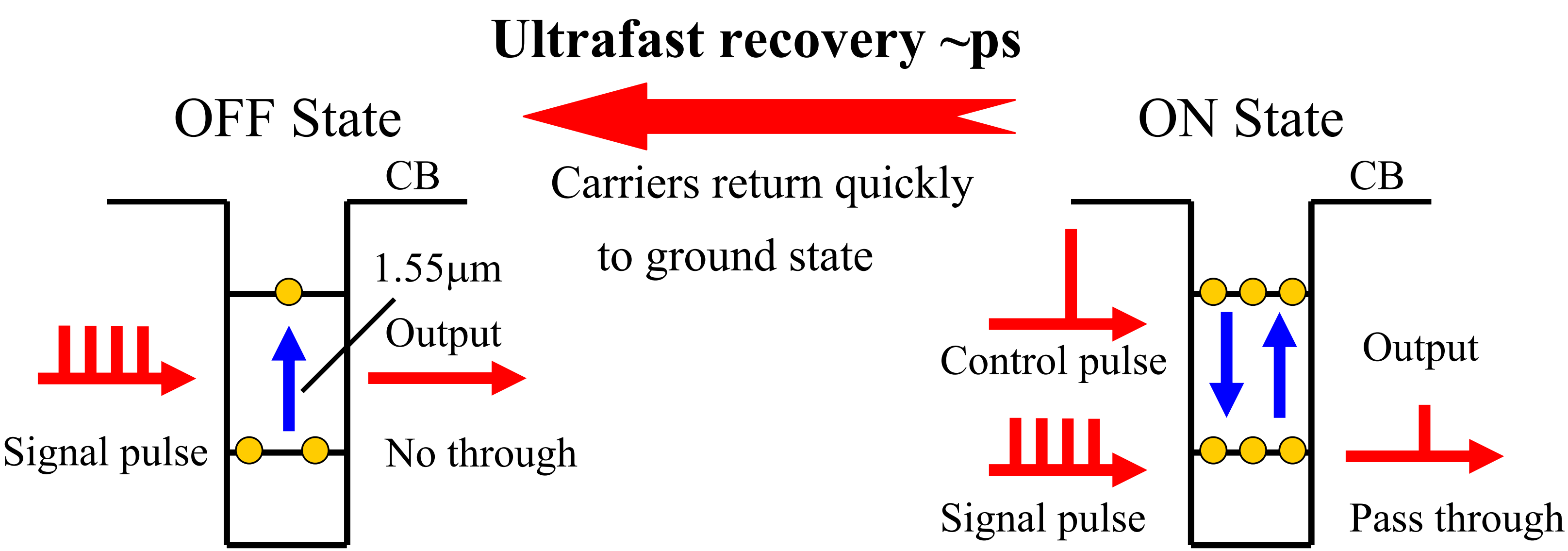
ISBT all-optical switch

Principle: ISB abs. Saturation and ultrafast recovery



What's material requirement ?

- **Using at optical communication wavelength of 1.55μm**

  Large conduction band offset

- **Ultrafast response (sub ps)**

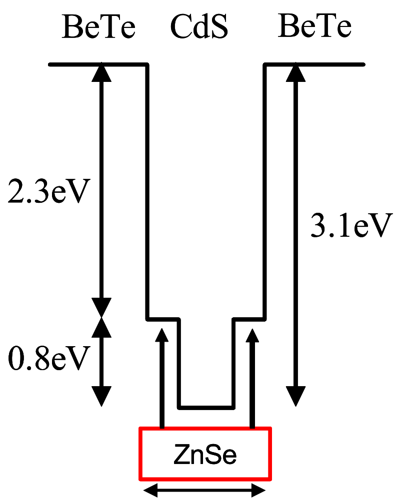
  Large electron-LO phonon interaction

(CdS/ZnSe)/BeTe II-VI QW

Introduction: Quantum well structure

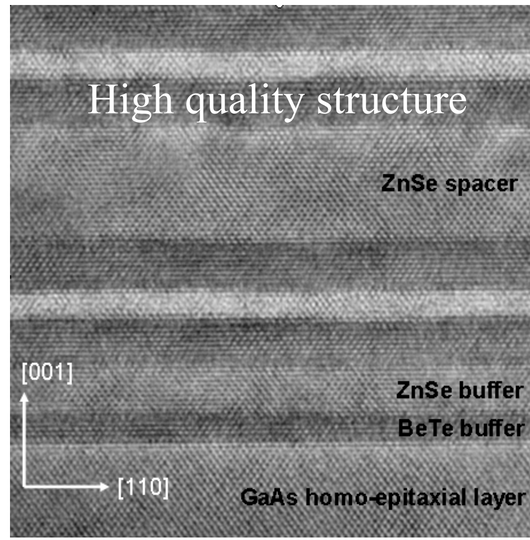
BeTe/ZnSe/CdS/ZnSe/BeTe

15ML/1ML/2ML/1ML/15ML



doping $ZnCl_2$ ~1×10^{19} (cm^{-3})

Bright field TEM image



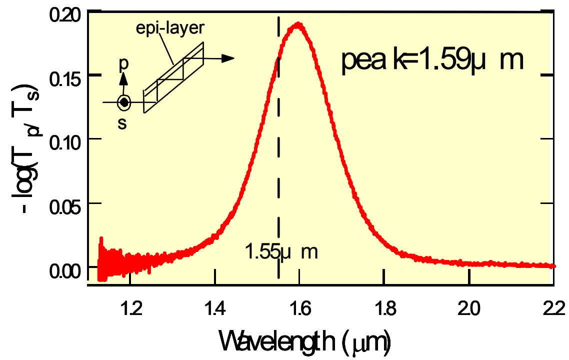
QW

BeTe barrier
ZnSe inter layer
CdS well
ZnSe inter layer
BeTe barrier

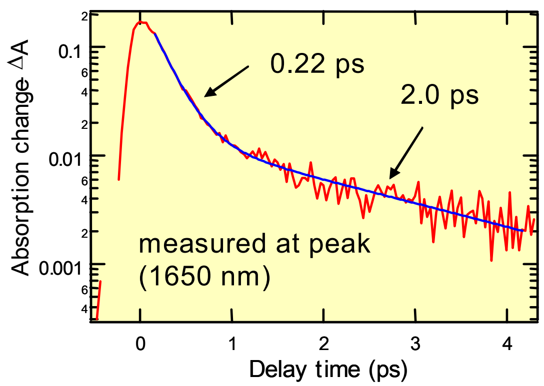
- Large conduction band offset between BeTe barrier and CdS well (3.1eV)
  → ISB absorption as short as 1.55μm
- CdS well : higher ionic material
  → Large electron-LO phonon interaction
- Grown on GaAs substrate with lattice match

ISBT in II-VI (CdS/ZnSe)/BeTe QWs

ISB absorption



ISB absorption recovery



R.Akimoto *et al*., ECOC (2004)

- 1.59μm absorption

  Covering the 1.55μm wavelength

- Ultrafast relaxation

  Sub ps carrier relaxation time

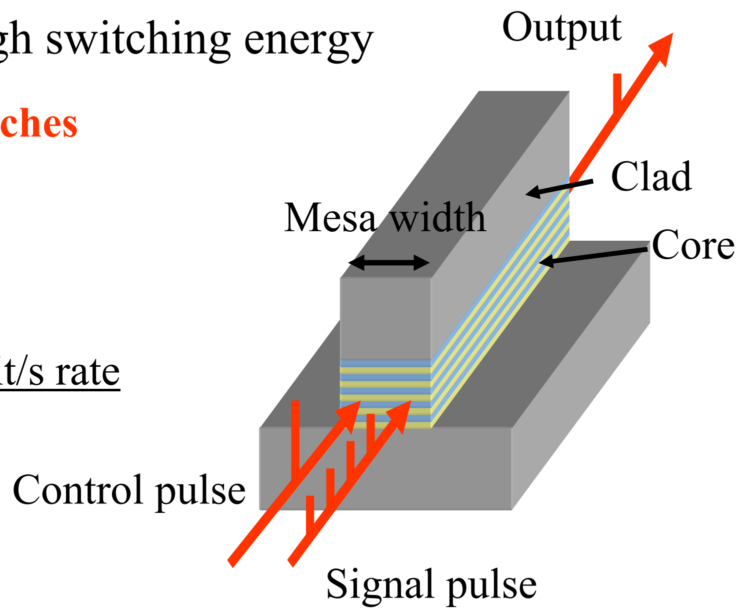
High bit-rate operation above 100Gbit/s

The problem of ISBT optical switch ➡ High switching energy

ISBT optical waveguide switches

Material systems	GaN	InGaAs	II-VI
Switching energy	**High**	**moderate**	**low**
	100pJ	32pJ	4pJ

<u>If the switching energy is 100pJ with 100bit/s rate</u>
<u>the mean power become 10W!</u>



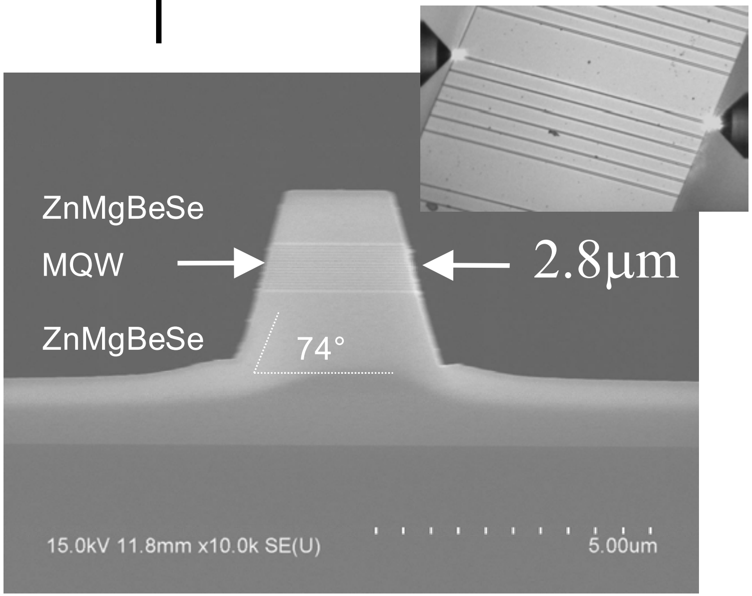
- Reduce the switching energy

(1) Efficiency absorption saturation by strong light confinement

(2) Low propagation loss waveguide

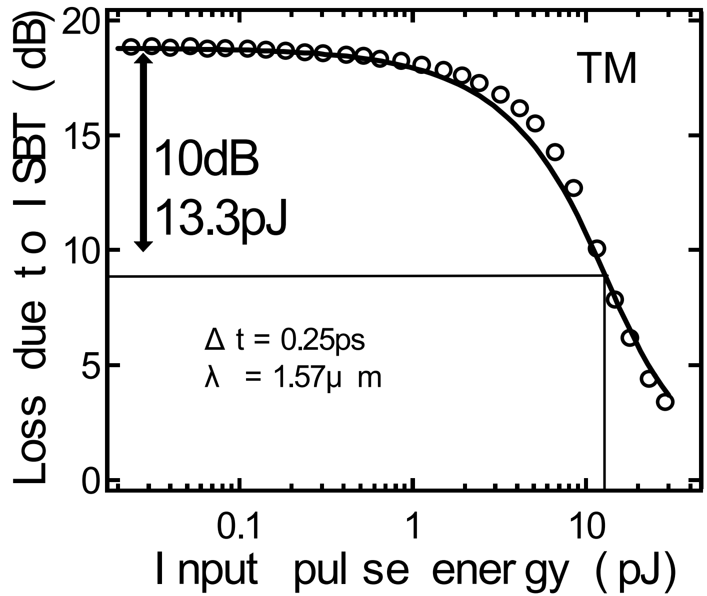
(3) Control the relaxation time of ISBT

Switching energy of ISBT optical switch



K.Akita et al., JJAP(2006)

ICP dry etching BCl_3/Ar



R.Akimoto et al., APL. 87, 181104 (2005)

Switching extinction ratio : transmissivity change by absorption saturation

10dB at 13.3 pJ still high for practical application (10dB@1pJ)

- Improve for absorption saturation energy more efficiency

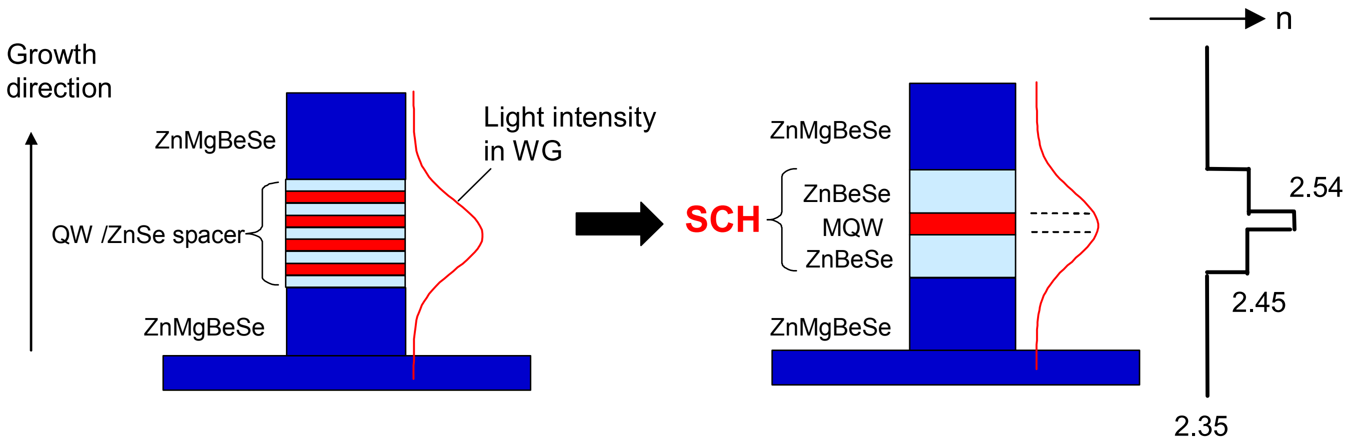
Core structure Mesa width QW strucutre

Waveguide core structure for low switching energy

Uniform

SCH

(Separate Confinement heterostructure)



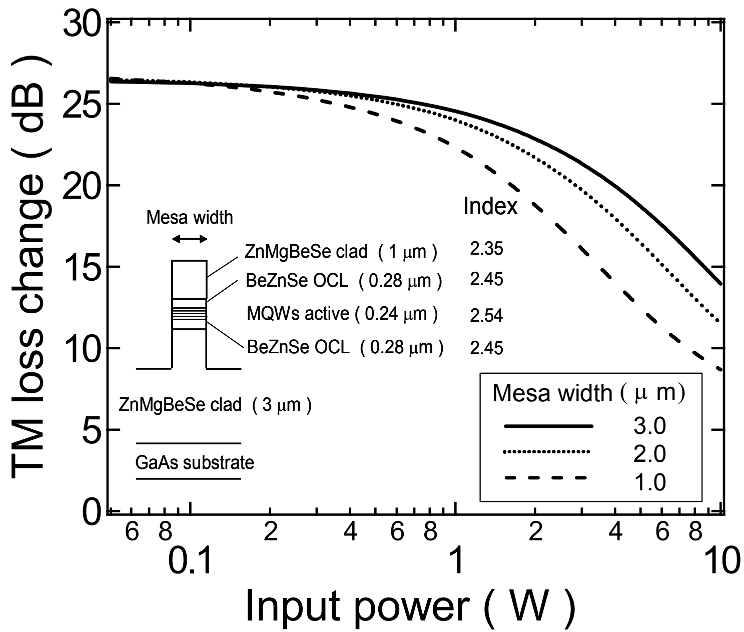
Set active layer middle of core ➡ High light intensity

More interaction electron & light (~30%)

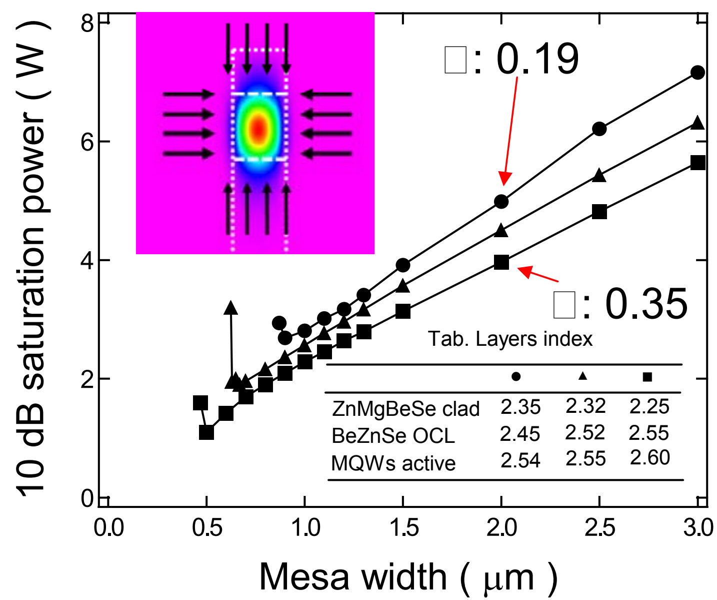
<u>SHC is effective for low switching energy</u>

Low switching energy by strong light confinement

Absorption saturation curve

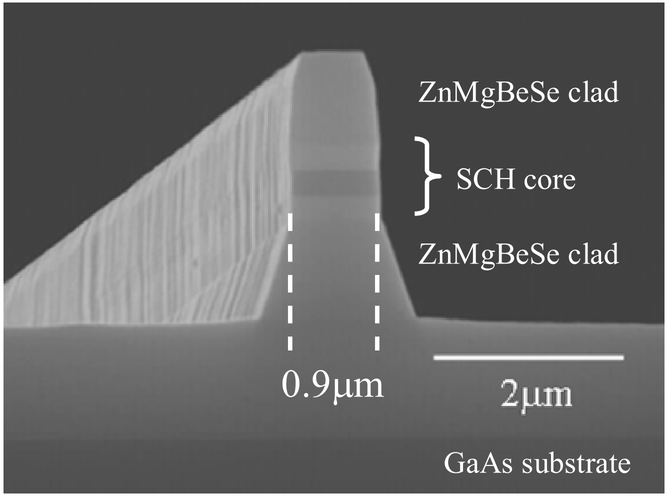


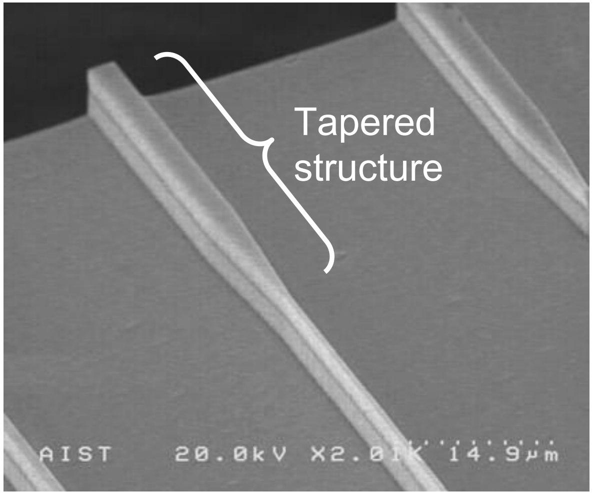
10dB saturation energy



- High index contrast between active and clad layers
- Narrow mesa width (~1µm) with strong light confinement

Narrow mesa waveguide





K.Akita et al., Electron lett. 42, 1352 (2006)

- Fabricated by BCl_3/Ar based inductively coupled plasma(ICP) dry etching
- Mesa width narrow to ~**0.9μm**
- Tapered structure : To reduce coupling loss with optical fiber

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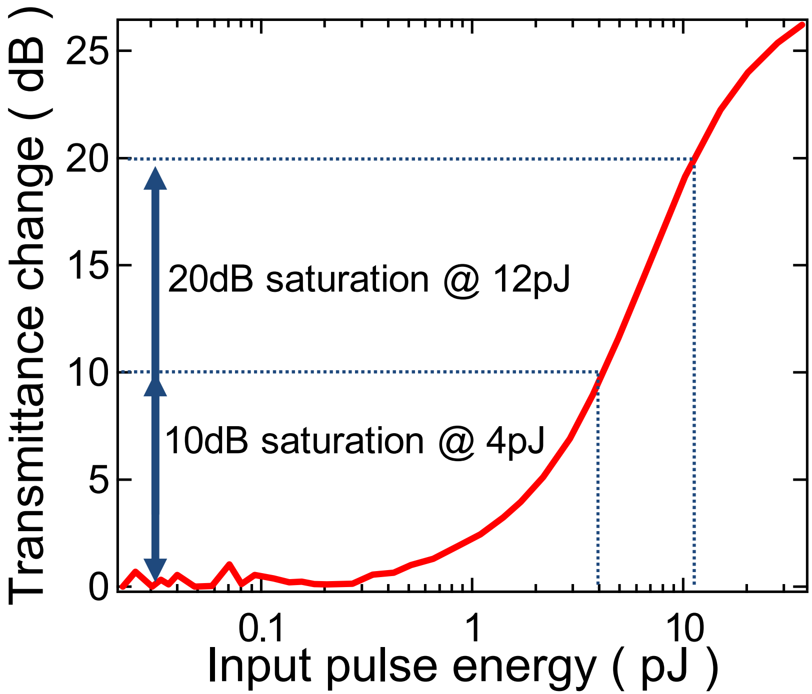
ISB absorption saturation in narrow mesa waveguide



- Saturation energy

  •10dB@4pJ

  K.Akita et al., Electron lett. 42, 1352 (2006)

  •20dB@12pJ

  Most fast date:10dB@2pJ

  G.W.Cong et al., opt express (2007)

  SCH & Narrow mesa effect !!

  13.1→4PJ : 30%

  •Smaller than other system

  GaN >> II-VI InGaAs > II-VI

- Practical application required

  10dB @ 1pJ

- Optimization

  QW structure and Waveguide structure

Improve

Running work !!

QW structure & Waveguide structure

QW for low switching energy

Saturation intensity

$$I_s = \frac{cn\varepsilon_0\hbar^2}{2\mu^2 T_1 T_2}\Delta t_p$$

T_1: Electron relaxation time

T_2: Phase relaxation time

Δt_p :pulse width

Fast relaxation time ➡ I_s : High

(CdS/ZnSe)/BeTe: ~0.2ps

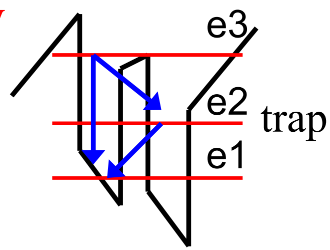
- How reduce the saturation energy ?

3 level coupled QW

e3 ➡ e2 ➡ e1

Trap carrier at e2

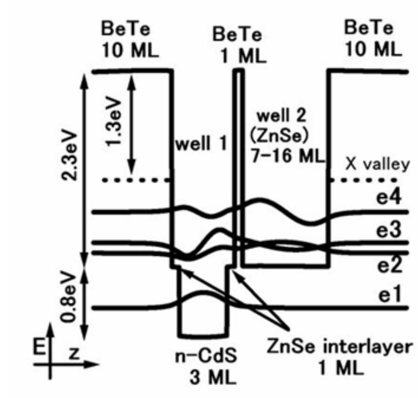
Slow decay occur

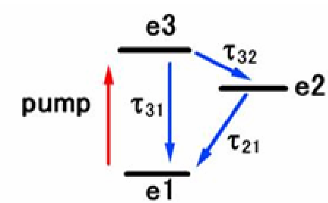


Greg Sun et al., APL. 87, 201108 (2005)

II-VI coupled QW

BeTe/ZnSe/CdS:well 1/ZnSe/BeTe/ZnSe:well 2



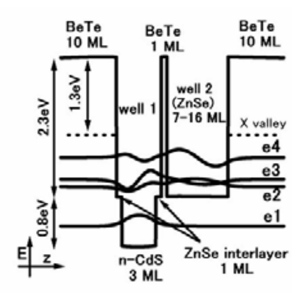


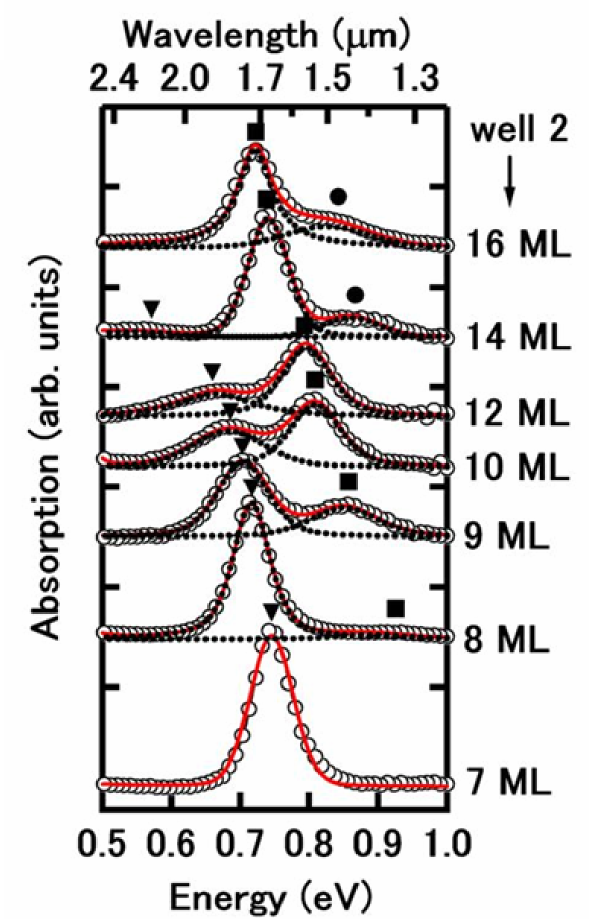
(CdS/ZnSe)/BeTe QW

ZnSe/BeTe QW

} **coupling**

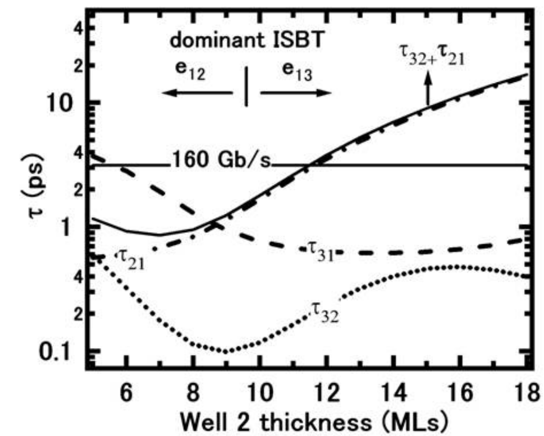
Absorption & relaxation time of CQW

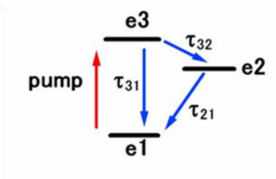




G.W.Cong et al., APL. 90, 181919 (2007)

relaxation time





- Absorption spectrum

  2 peak position ➡ Strong coupling

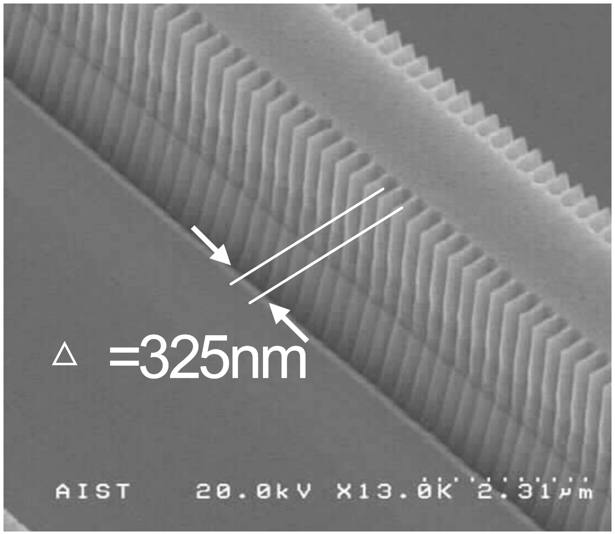
- Aim at 160Gbit/s operation

  τ=3ps @ Well2:12ML

Feasible for 160 Gbit/s operation

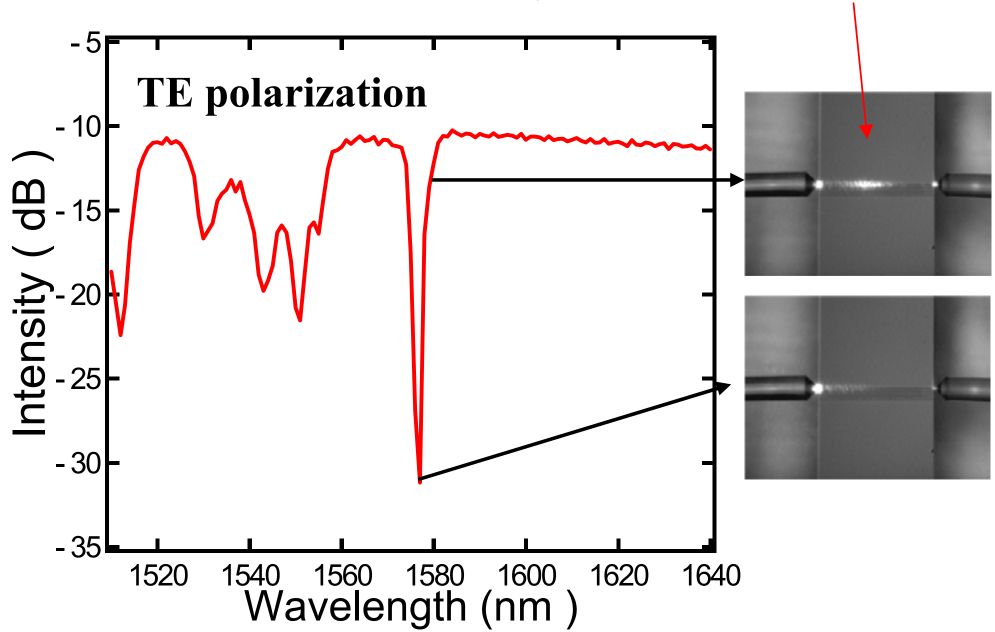
Optical confinement for forward direction of waveguide by DFB structure

Vertical grating DFB waveguide



Transmissivity

Light accumulation



- Waveguide with DFB structure

  Light confinement for forward direction by DFB

- Light accumulation near the stop band

  To more efficiency absorption saturation

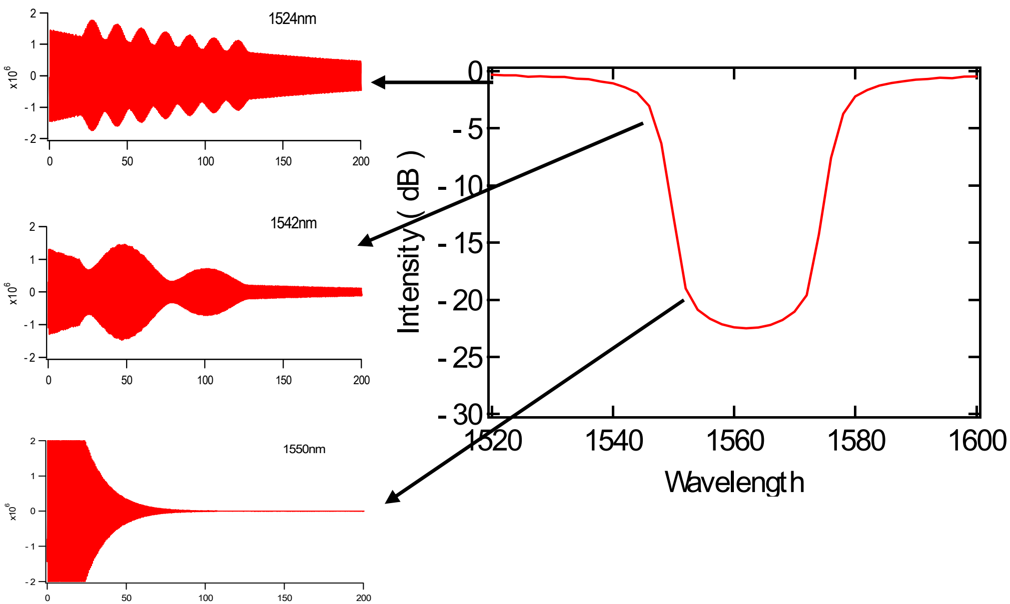
- New switching ?

  Stop band shift by nonliner effective index change!

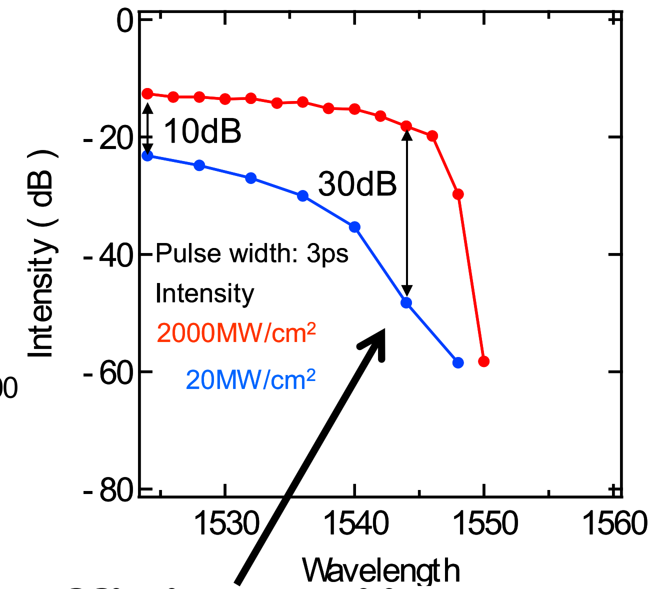
DFB effect for low switching energy

1D FDTD simulation

Electric filed intensity of waveguide



Calculation of DFB effect



3 times efficiency !!

DFB structure for low switching energy

Summary

- Waveguide toward device application

  Successful fabrication of II-VI-based ISBT narrow-mesa waveguide with strong light confinement

- Low switching energy characteristics in ISBT waveguide

  10dB@4pJ (1.62μm) **Lowest switching energy in ISBT switch**

- Produce the II-VI coupled QW for low saturation energy

  Control the ISBT relaxation time (0.2→3ps)

- Produce the DFB waveguide for low switching energy

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Thank you

for your attention !!

Switching characteristics: comparison

System	InGaAs/ AlAsSb (c- DQW)	GaN/ AlGaN	(CdS/ ZnSe)/ BeTe
	FESTA	Toshiba	AIST
10dB satration (pJ)	32 ① moderate	100 ② high	4 low
Switching time (ps)	0.69 ~ 2 moderate	0.16 ~ 0.4 ultrafast	~ 0.2 ultrafast
Remark	TPA	loss from dislocation	

①S.Sekiguchi *et al.*, OFC, 2005 ②N.Iizuka *et al.*, Opt.Express, 2005

③K.Akita et al., Electron lett. 42, 1352 (2006)

Two photon absorption of InGaAs system

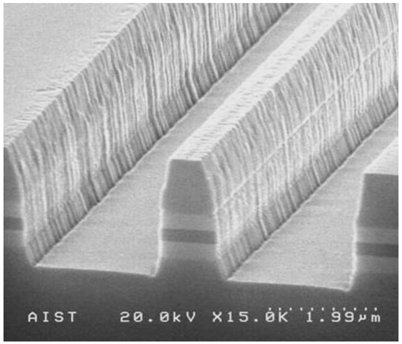
⇔ **II-VI system** is wide bandgap (2.3eV)

TM loss from dislocation of GaN system

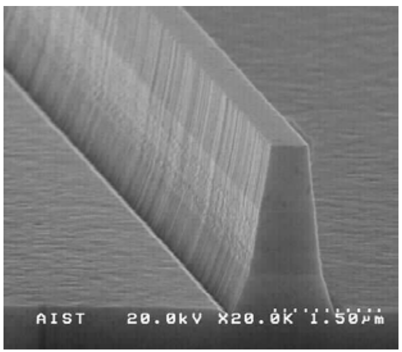
⇔ **II-VI system** can Grow on GaAs substrate with lattice matched

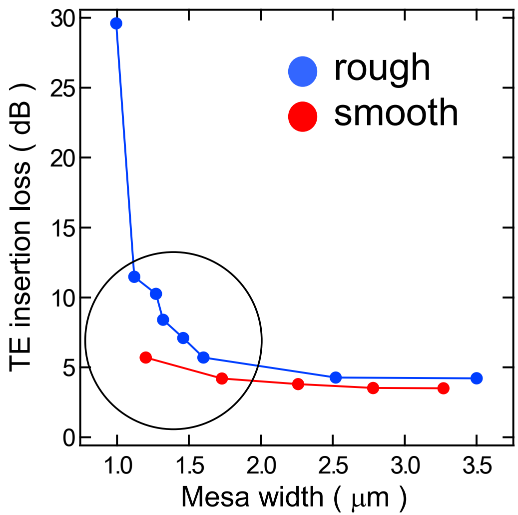
Narrow mesa effect for insertion loss

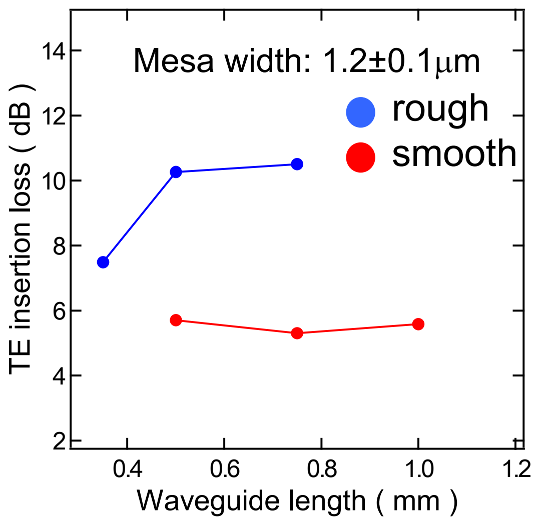
Rough sidewall



Smooth sidewall







- Mesa width dependence

  Mesa width < 2µm rough sidewall: large insertion loss

- Propagation loss

  Smooth: Not depend on waveguide length

  Rough : Propagation loss 7.5dB/mm

Narrow mesa effect for absorption saturation