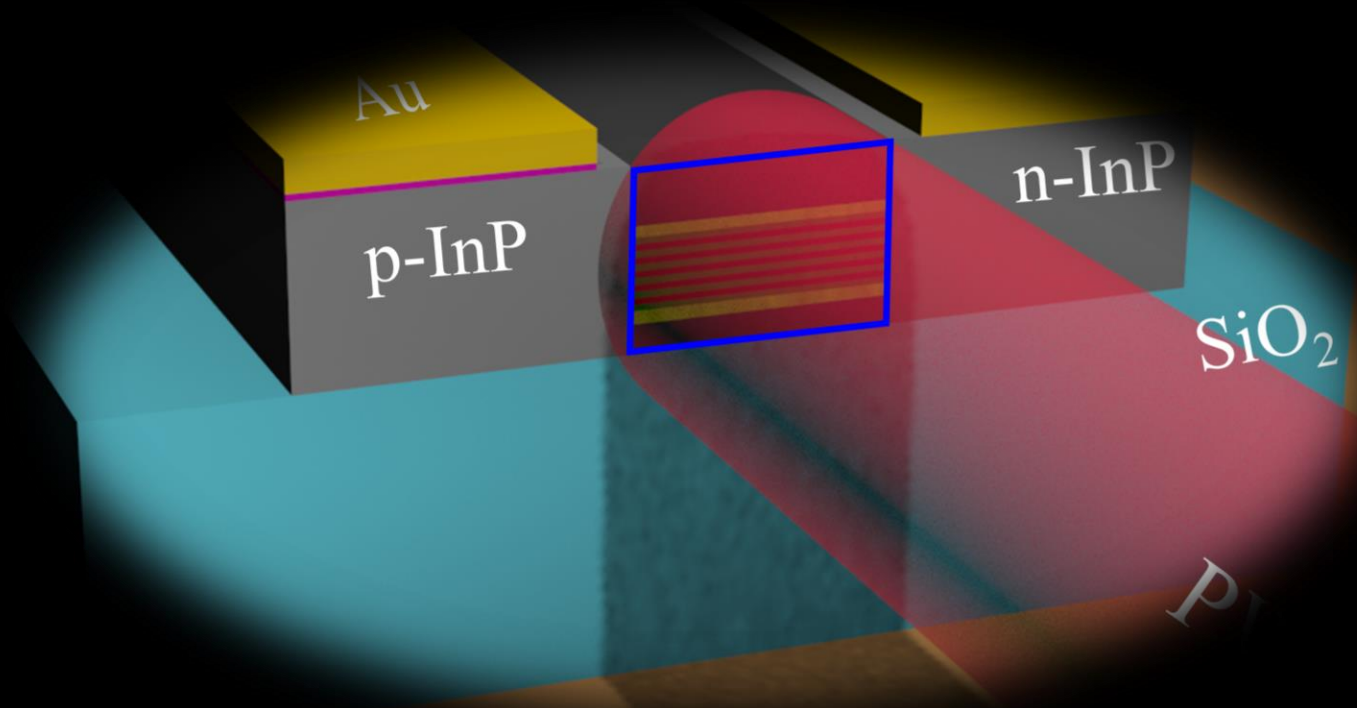




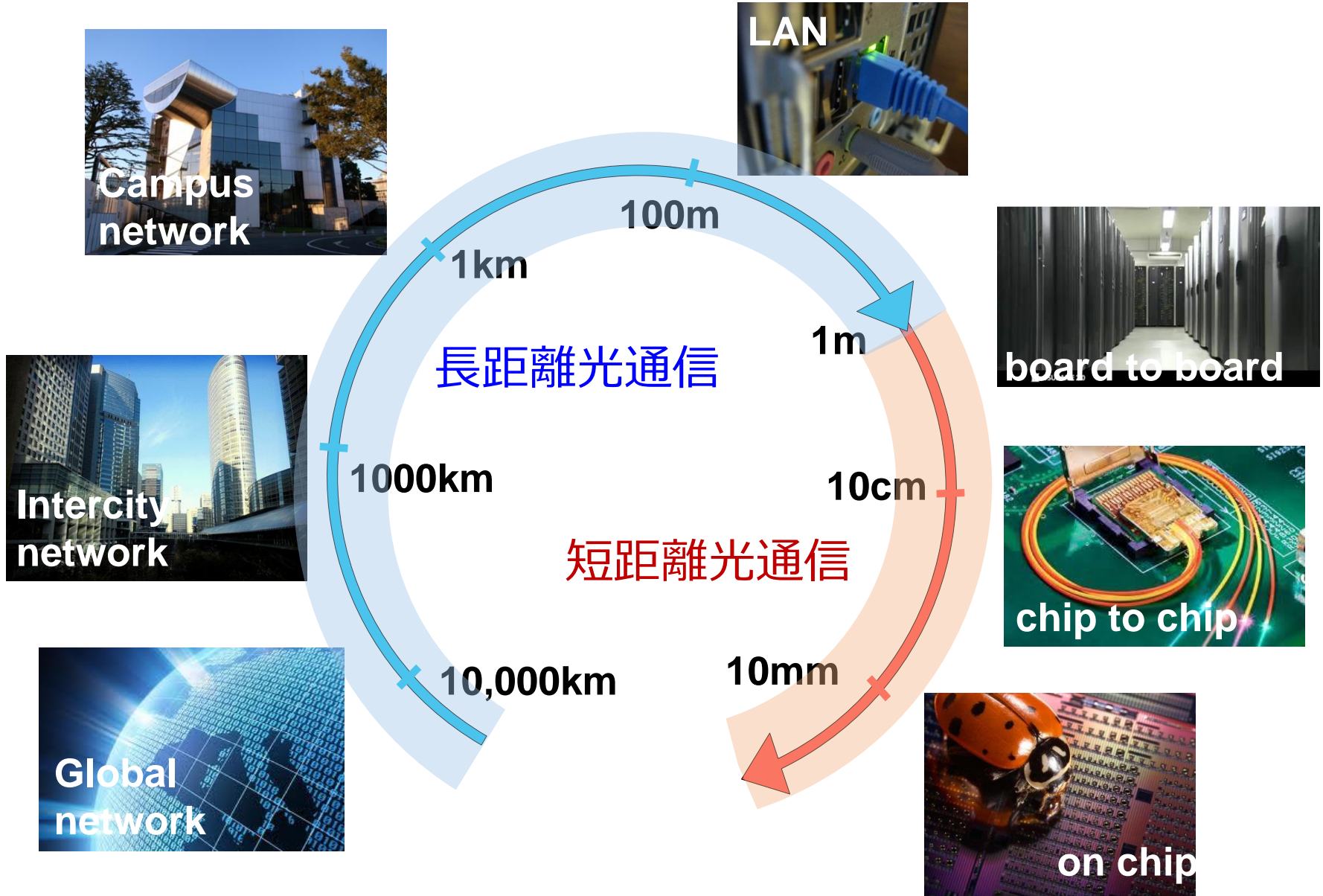
# フォトリックワイヤーボンディング によるSi基板上III-Vチップ間の光伝搬



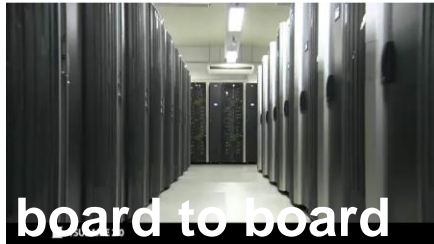
Tomohiro AMEMIYA<sup>1,2</sup>

<sup>1</sup>*Institute of Innovative Research (IIR), Tokyo Institute of Technology*

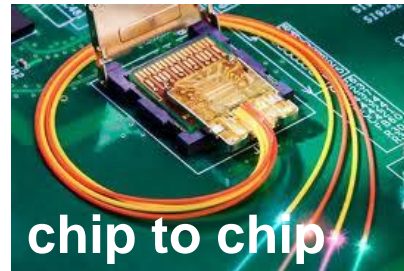
<sup>2</sup>*Department of Electrical and Electronic Engineering, Tokyo Institute of Technology*



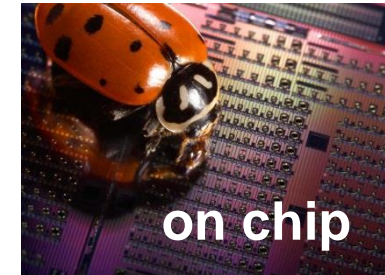
TSUBAME 2.0  
@ Tokyo Tech



Light Peak @ Intel  
EXTREME TECH



Optical chip @ Intel  
The Register



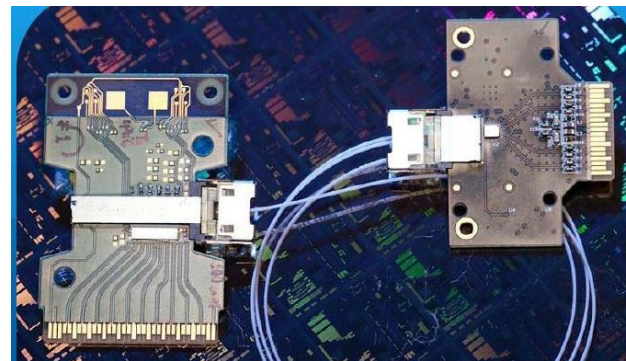
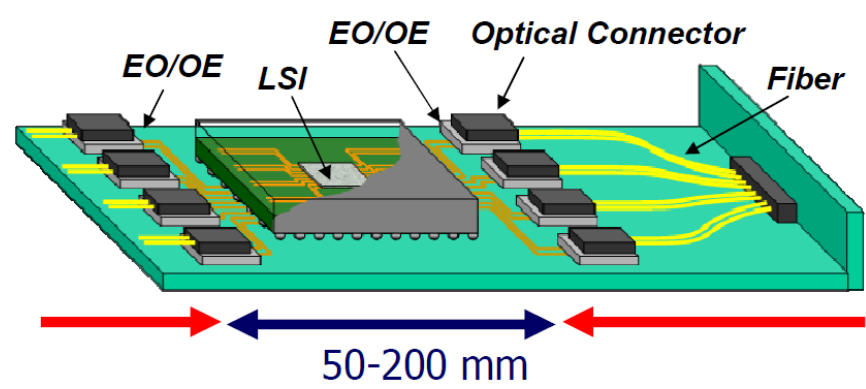
長距離から短距離へ

- ポート間光通信 (1 m)
- チップ間光通信 (10 cm)
- オンチップ光通信 (10-20 mm)

Photonic Wire  
Bonding

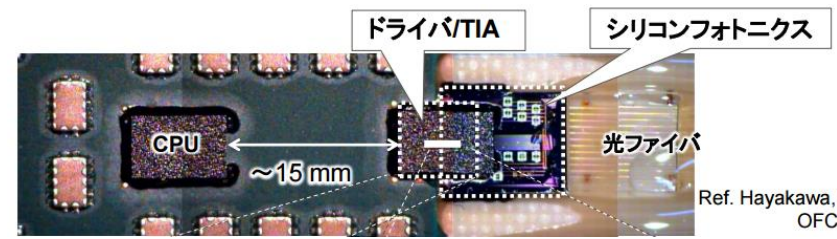
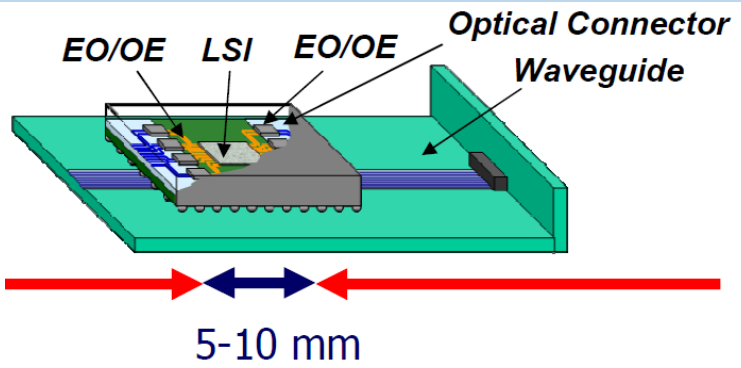
# 電気配線から光配線へ：短距離間伝送のための光

## ボード内光インターコネクション



Intel

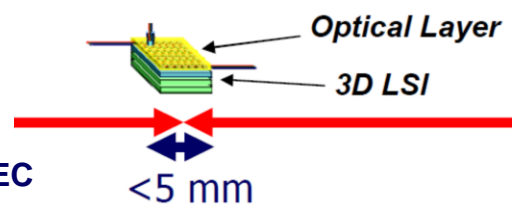
## インターポーザ内光インターコネクション



Ref. Hayakawa, et al. OFC2015

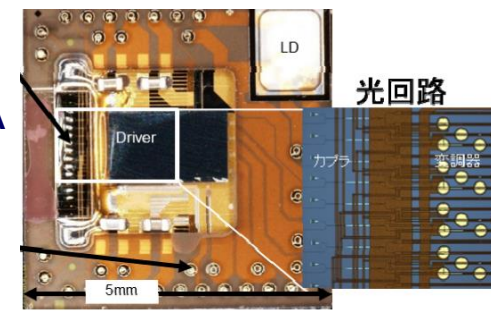
Fujitsu

## オンチップ光インターコネクション

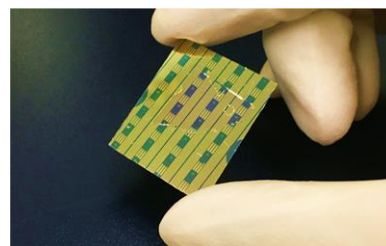


Ohashi et al, NEC

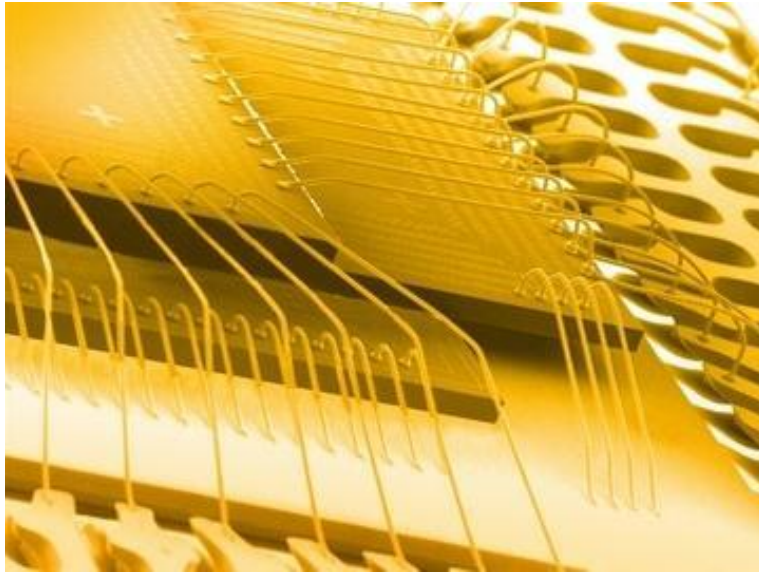
PETRA 東大



東工大



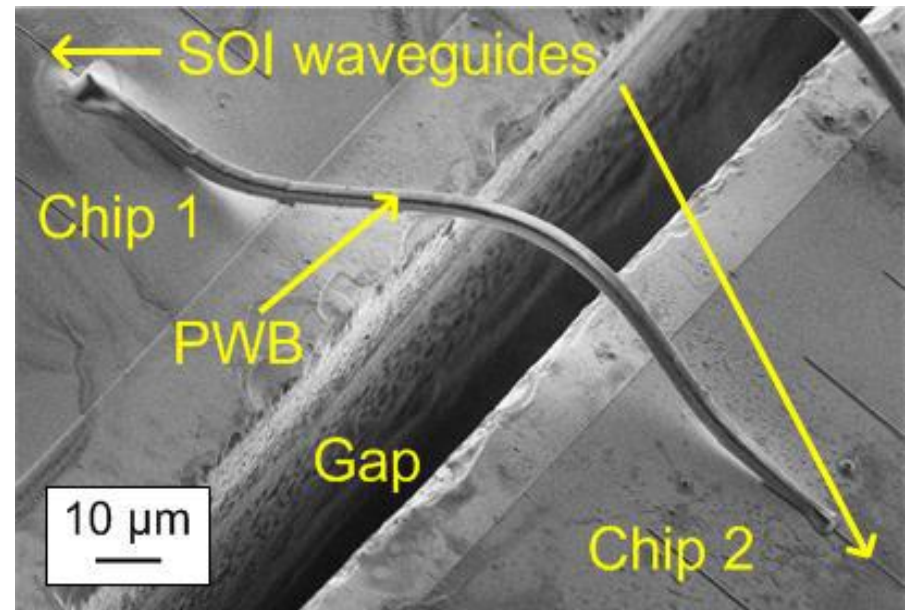




Kulicke&Soffa, <http://www.kns.com/>

## ◀ Classical: Electronic wire

- ✓ アルミニウム、銅、金
- ✓ ループ軌跡のタイト・コントロール
- ✓ 自動化作製

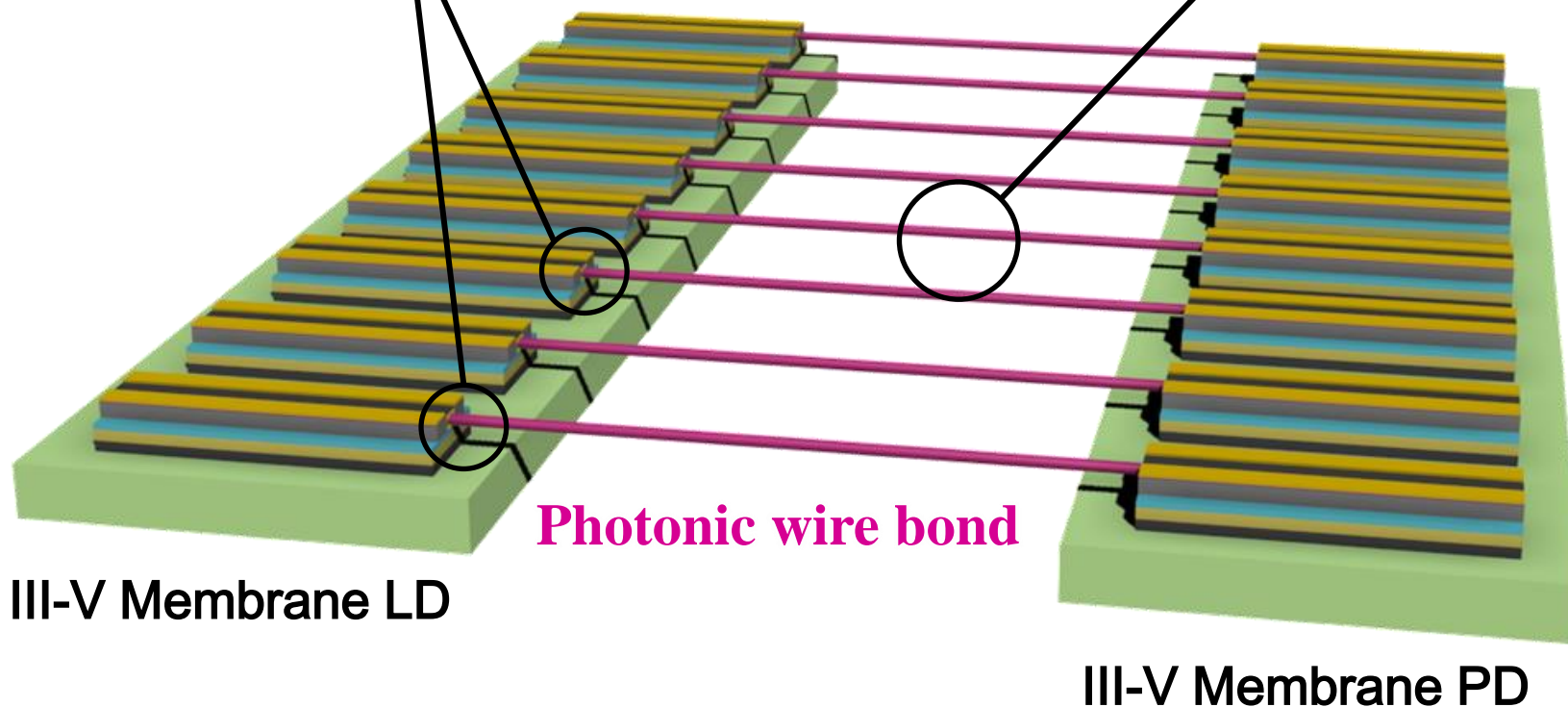


Karlsruhe Institute of Technology

## Novel: Photonic wire ▶

- ✓ 紫外線硬化樹脂SU-8
- ✓ 3Dフリーフォームボンディング
- ✓ シングルモード伝播可能

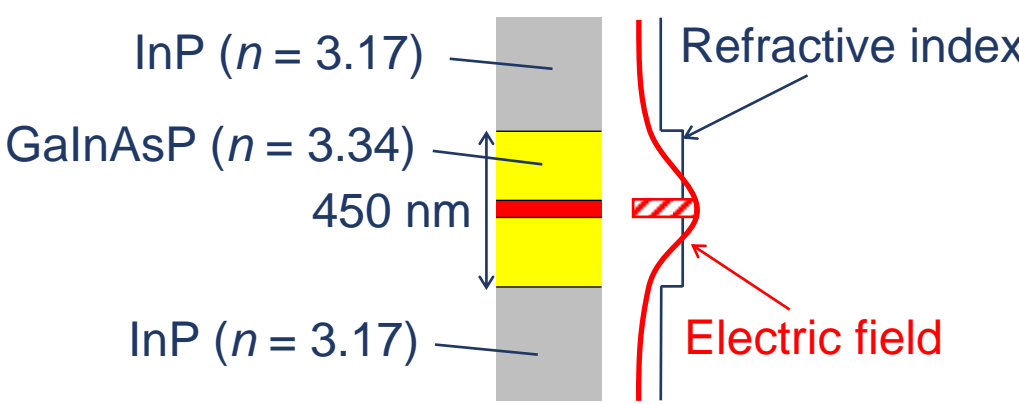
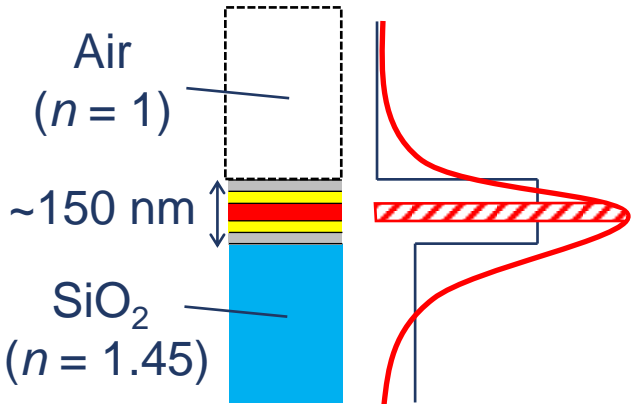
## フォトニックワイアボンディングによる異種材料光素子接続

結合損失の  
理論的検討PWBの作製法の確立及び  
光伝送の実測

III-V Membrane LD

III-V Membrane PD

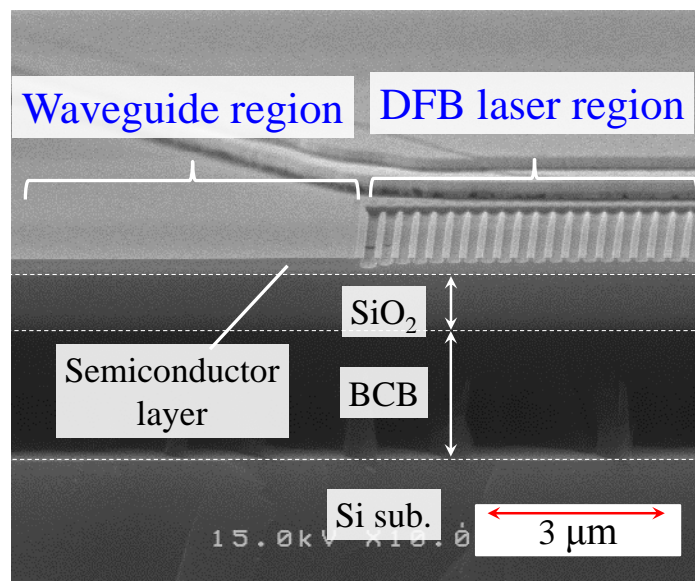
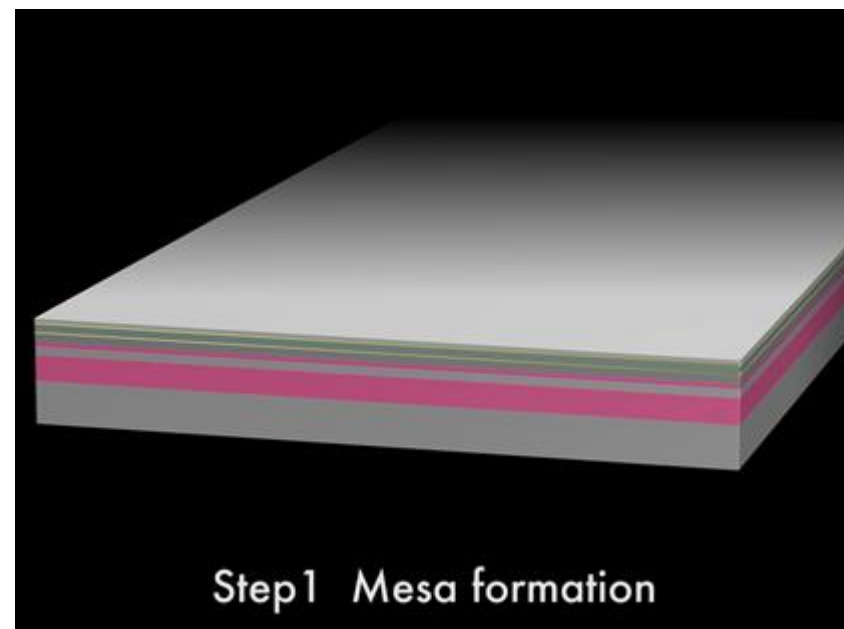
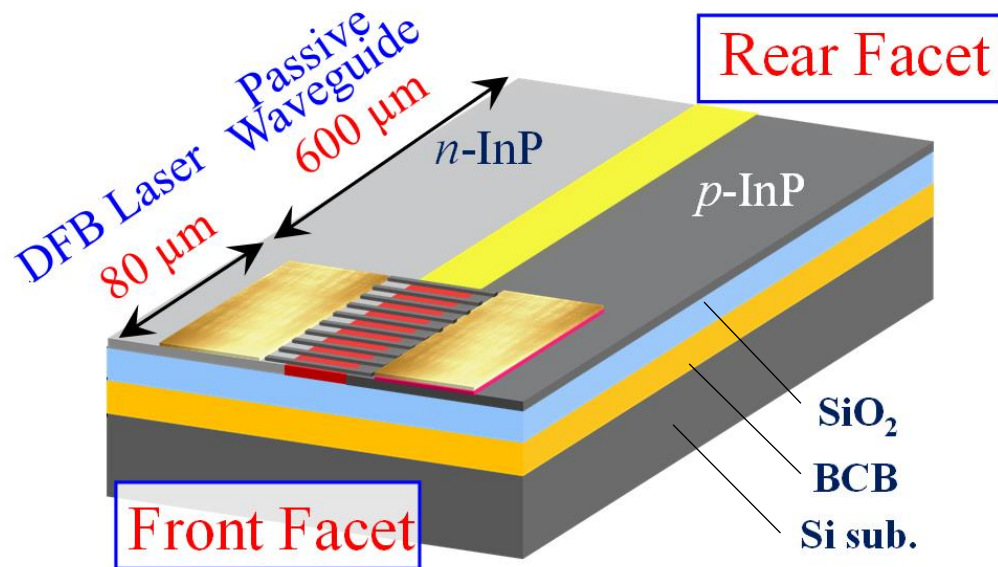
Photonic wire bond

Conventional PICs	Membrane PICs (MPICs)
 <p>InP (<math>n = 3.17</math>)</p> <p>GaInAsP (<math>n = 3.34</math>)</p> <p>450 nm</p> <p>InP (<math>n = 3.17</math>)</p> <p>Refractive index</p> <p>Electric field</p>	 <p>Air (<math>n = 1</math>)</p> <p>~150 nm</p> <p>SiO<sub>2</sub> (<math>n = 1.45</math>)</p> <p>Refractive index</p> <p>Electric field</p>
Index difference	$\Delta = 5\%$
Optical confinement	$\xi_{\text{act}} \sim 1\%/\text{well}$
	$\Delta = 40\%$
	$\xi_{\text{act}} \sim 3\%/\text{well}$

## 薄膜化による各種光デバイスのメリット

- 光源 活性層への閉じ込め係数増大に伴う低閾値化
- 受光器 吸収層への閉じ込め係数増加に伴う感度上昇と小型化

# 本研究で用いる光源の特徴



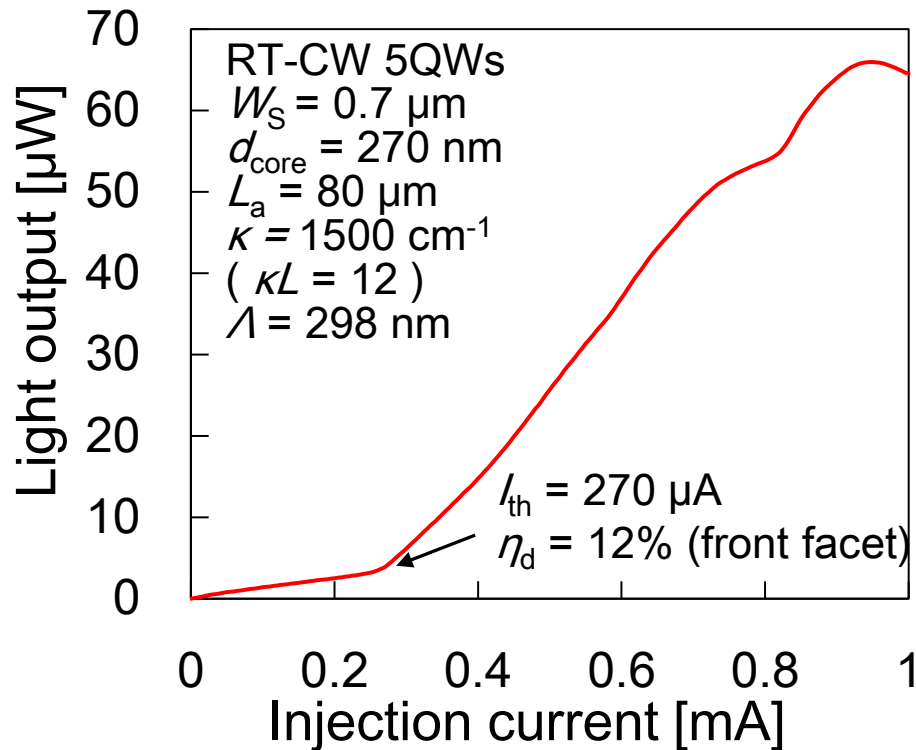
## DFBレーザ

- コア層270 nm, 共振器長 80  $\mu\text{m}$
- 回折格子周期 298 nm
- 表面回折格子深さ 約50 nm

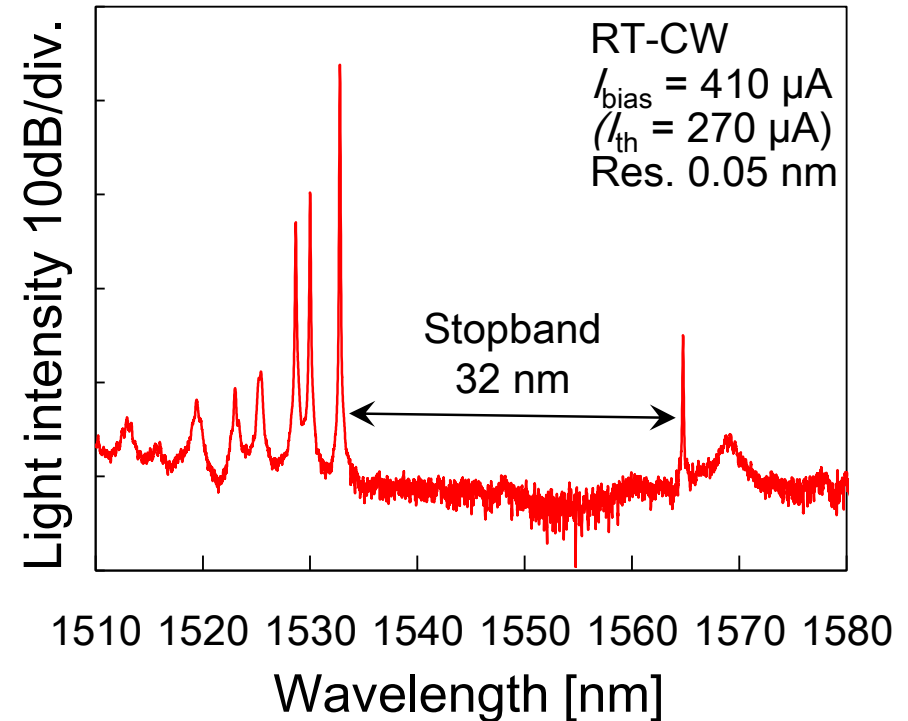


# 本研究で用いる光源の特性(1)

## 光出力特性

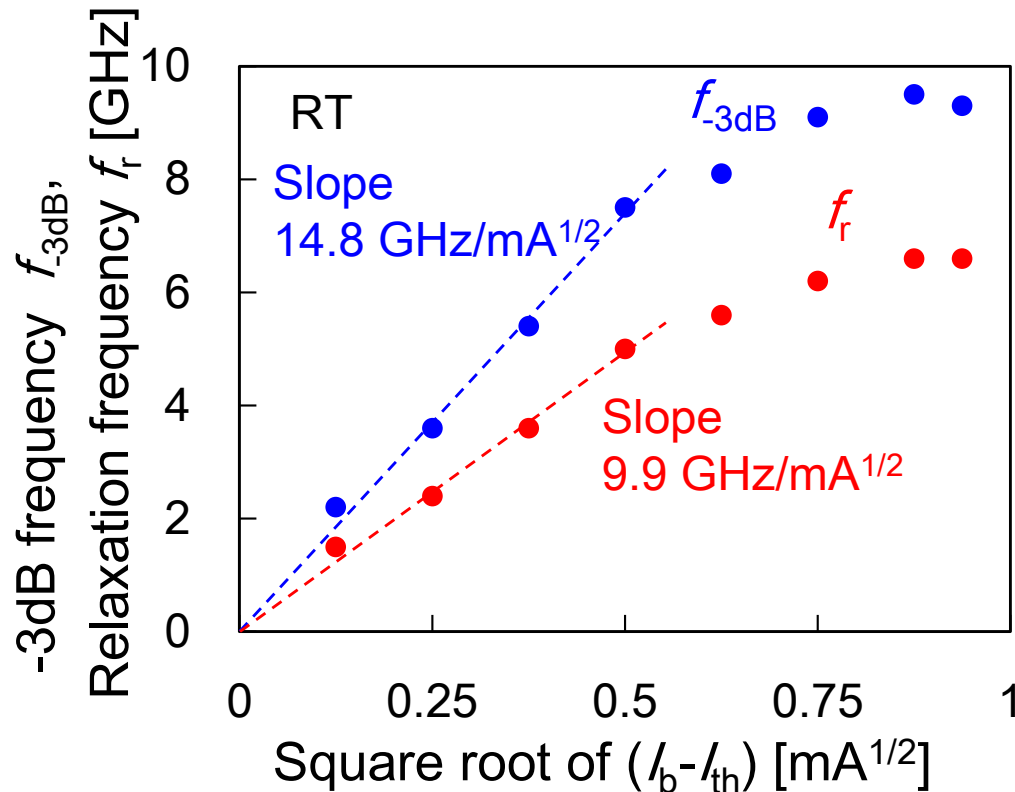


## 発振スペクトル特性



しきい値電流 :  $I_{\text{th}} = 270 \mu\text{A}$  ( $J_{\text{th}} = 96 \text{ A/cm}^2/\text{well}$ , 5QWs)  
 外部微分量子効率 :  $\eta_d = 12\%$  (front facet)  
 発振波長:  $1533 \text{ nm}$  @  $I_b = 410 \mu\text{A}$  ( $1.5 I_{\text{th}}$ ), Stopband :  $32 \text{ nm}$

# 本研究で用いる光源の特性(2)



半導体クラッド構造を用いた短共振器DFBレーザ

$f_r$  変調効率 : 4.8 GHz/ $\text{mA}^{1/2}$   
( AlGaInAs系活性層、  
共振器長100  $\mu\text{m}$  )

W. Kobayashi *et. al.*, *JSTQE* 19, 2013

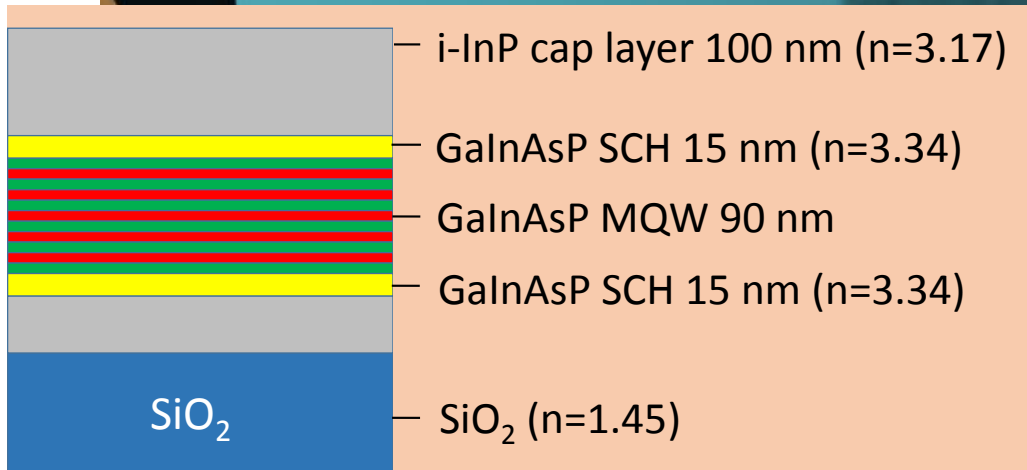
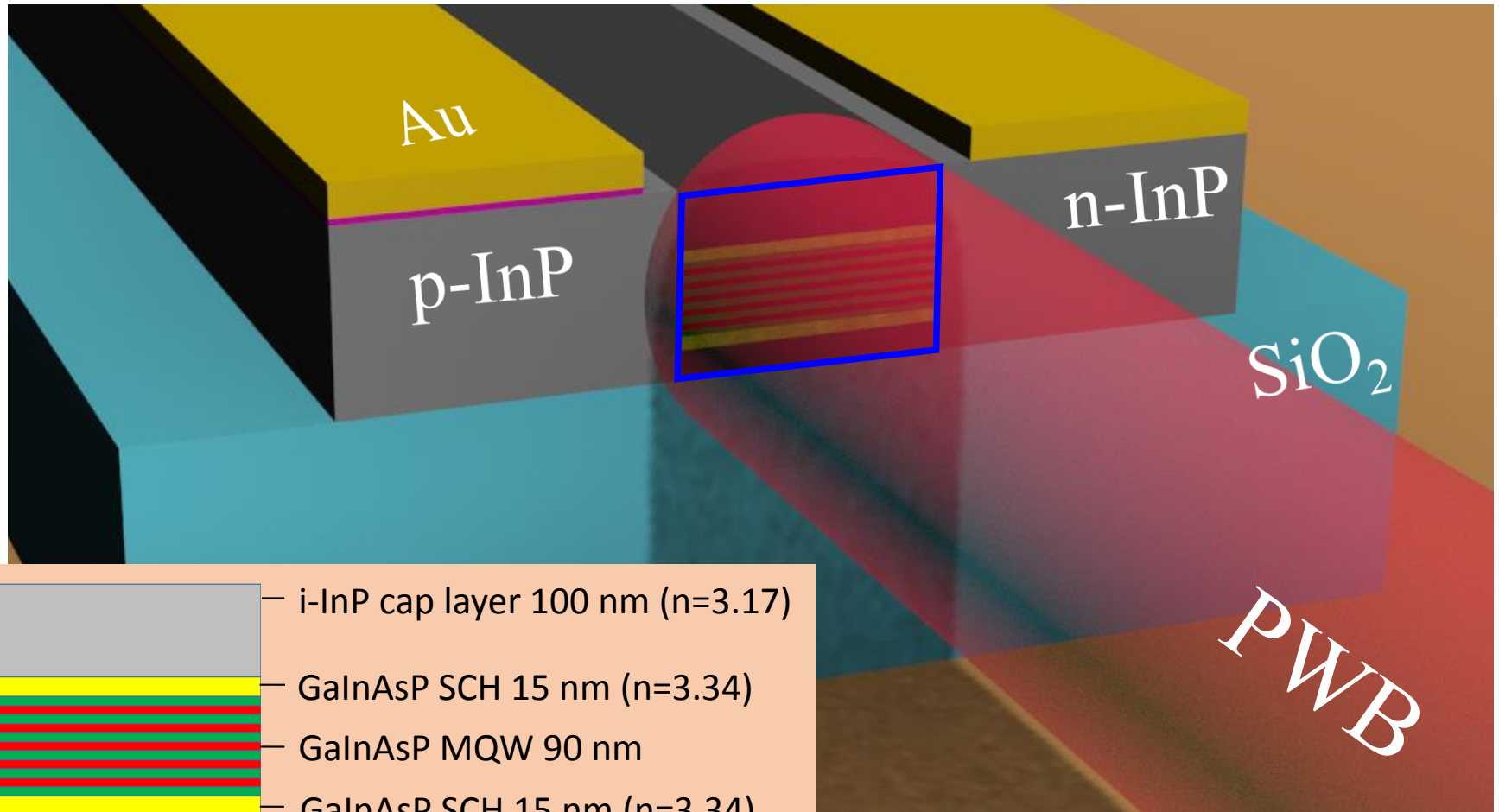
$f_r$  変調効率 : 2.3 GHz/ $\text{mA}^{1/2}$   
( GaInAsP系活性層、  
共振器長150  $\mu\text{m}$  )

S. Kanazawa *et. al.*, *ELEX* 12, 2015

電流変調効率 9.9 GHz/ $\text{mA}^{1/2}$

✓ 薄膜構造による強光閉じ込め ✓ 短共振器DFB構造

NTT reported  $f_r$  of 9.4 GHz/ $\text{mA}^{1/2}$  membrane DFB laser



PWB

SiO<sub>2</sub>

n-InP

p-InP

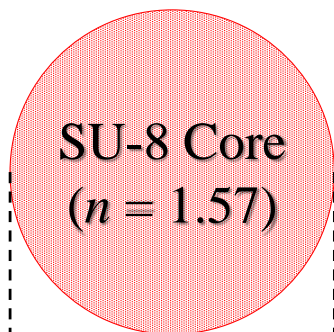
Au

SiO<sub>2</sub>

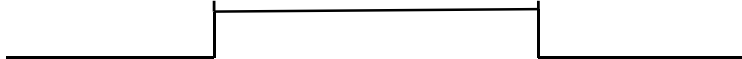
## Photonic Wire Bonding

Air Cladding  
( $n = 1$ )

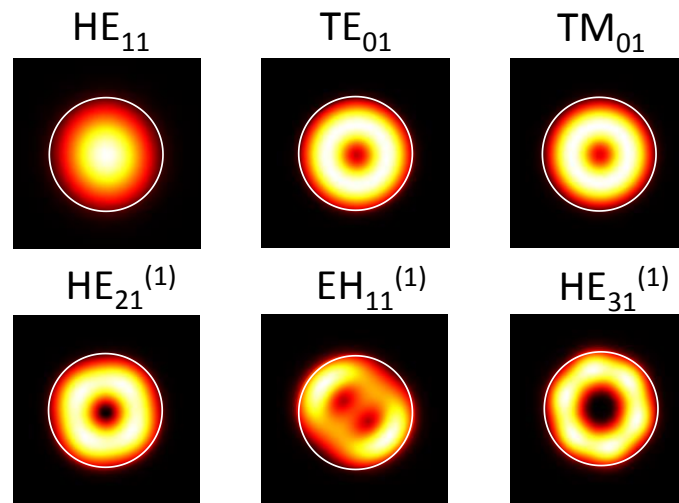
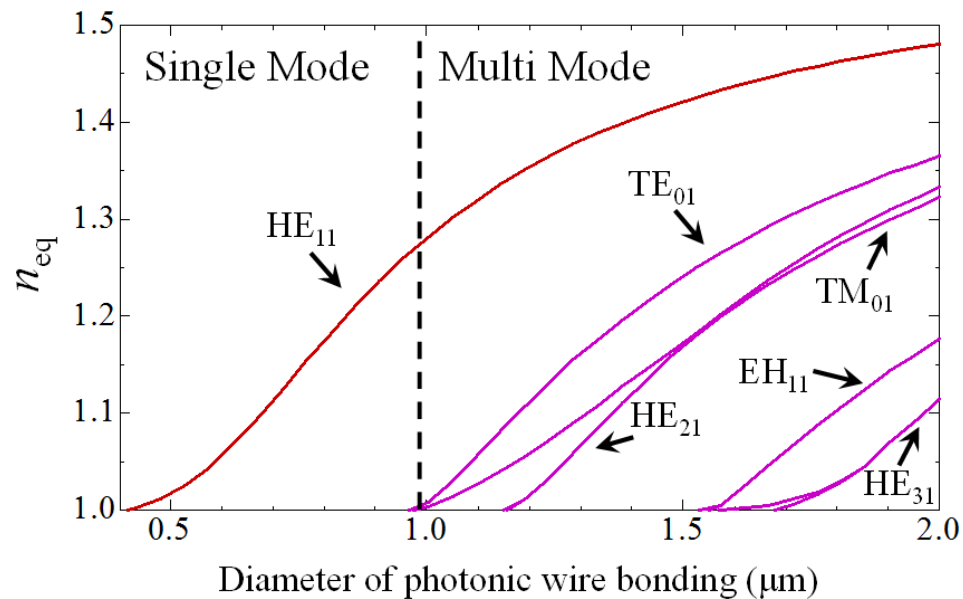
Cross  
Section



Refractive  
Index  
Profile



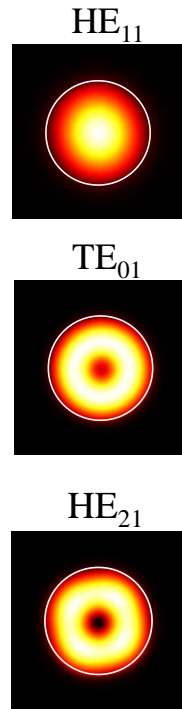
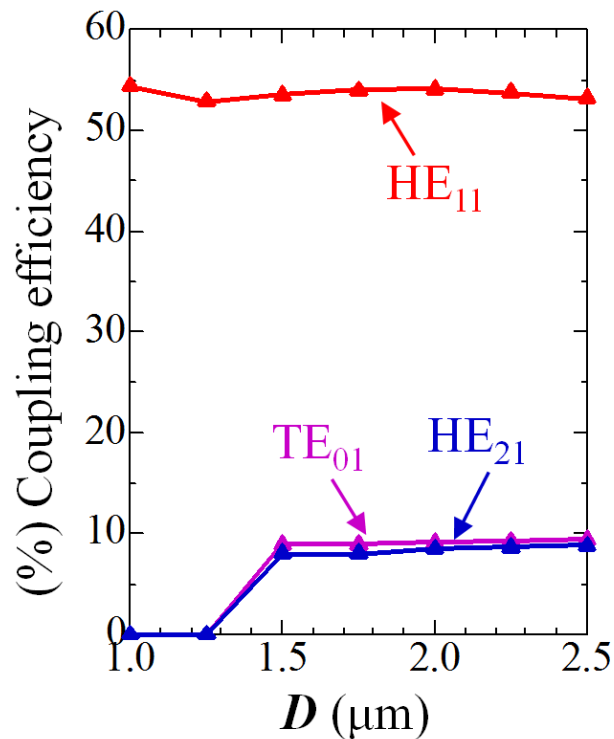
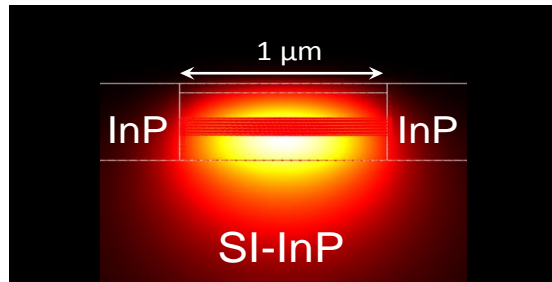
ステップインデックス型ファイバに類似する構造



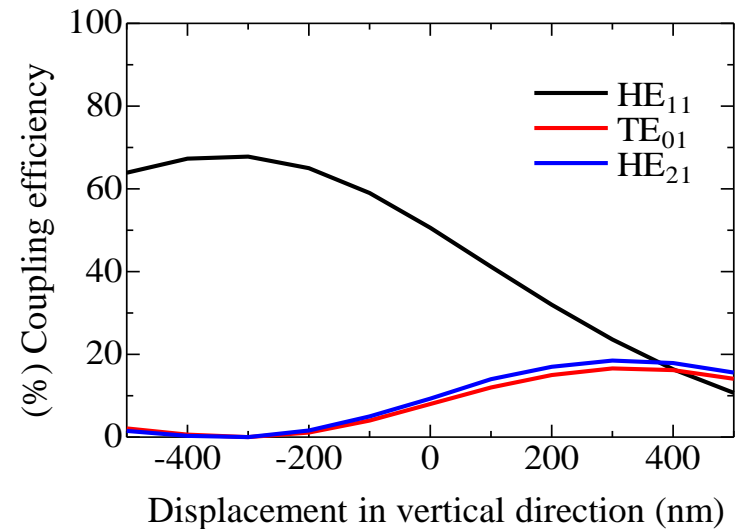
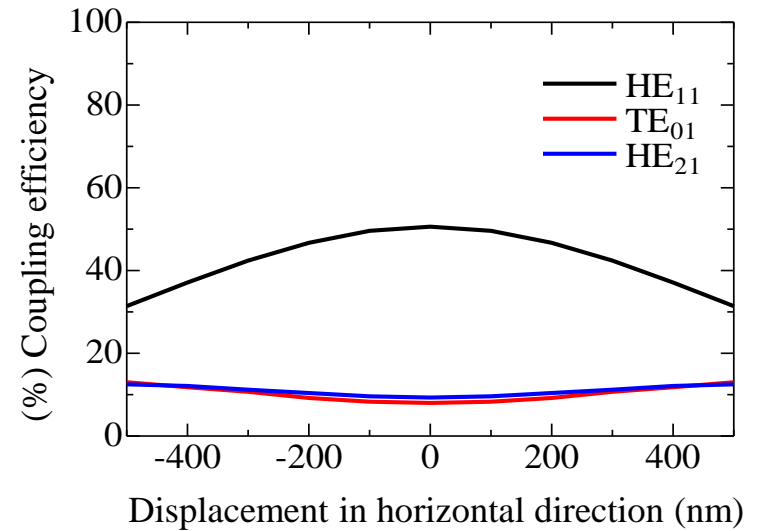


# PWBと光源の結合解析

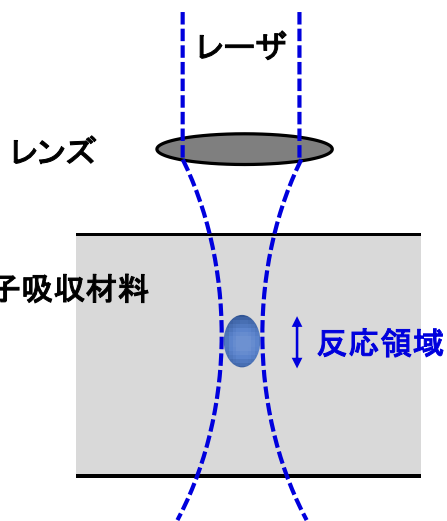
## 光源とのモード結合



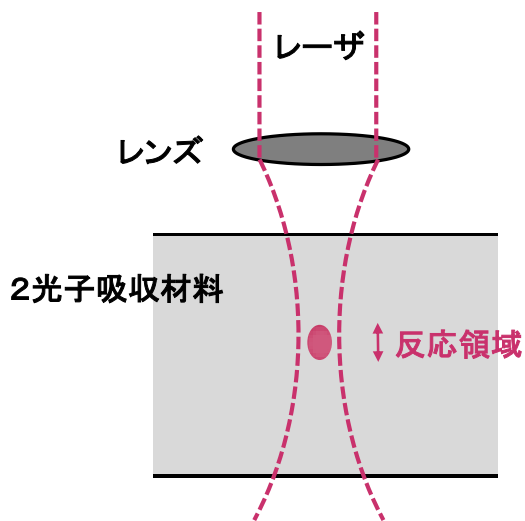
## PWBと光源の中心位置



## 単光子吸収と二光子吸収の比較



1光子吸収現象

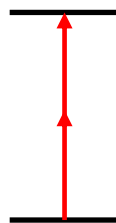
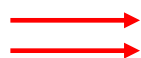


2光子吸収現象

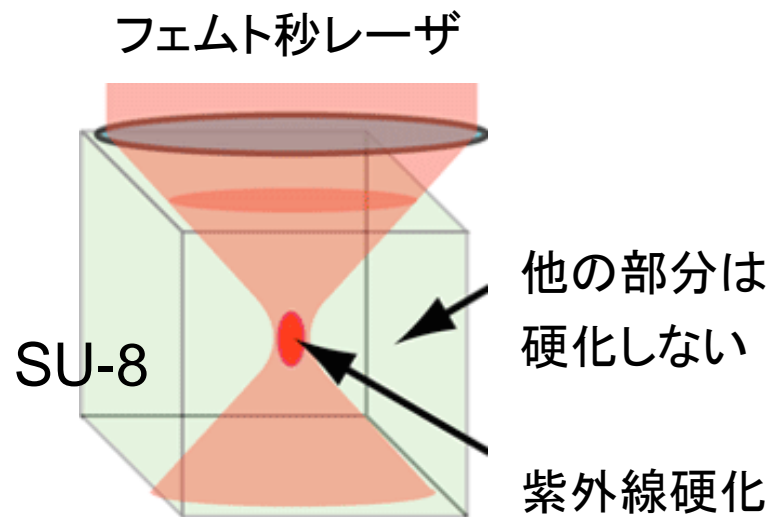
紫外光  
400 nm



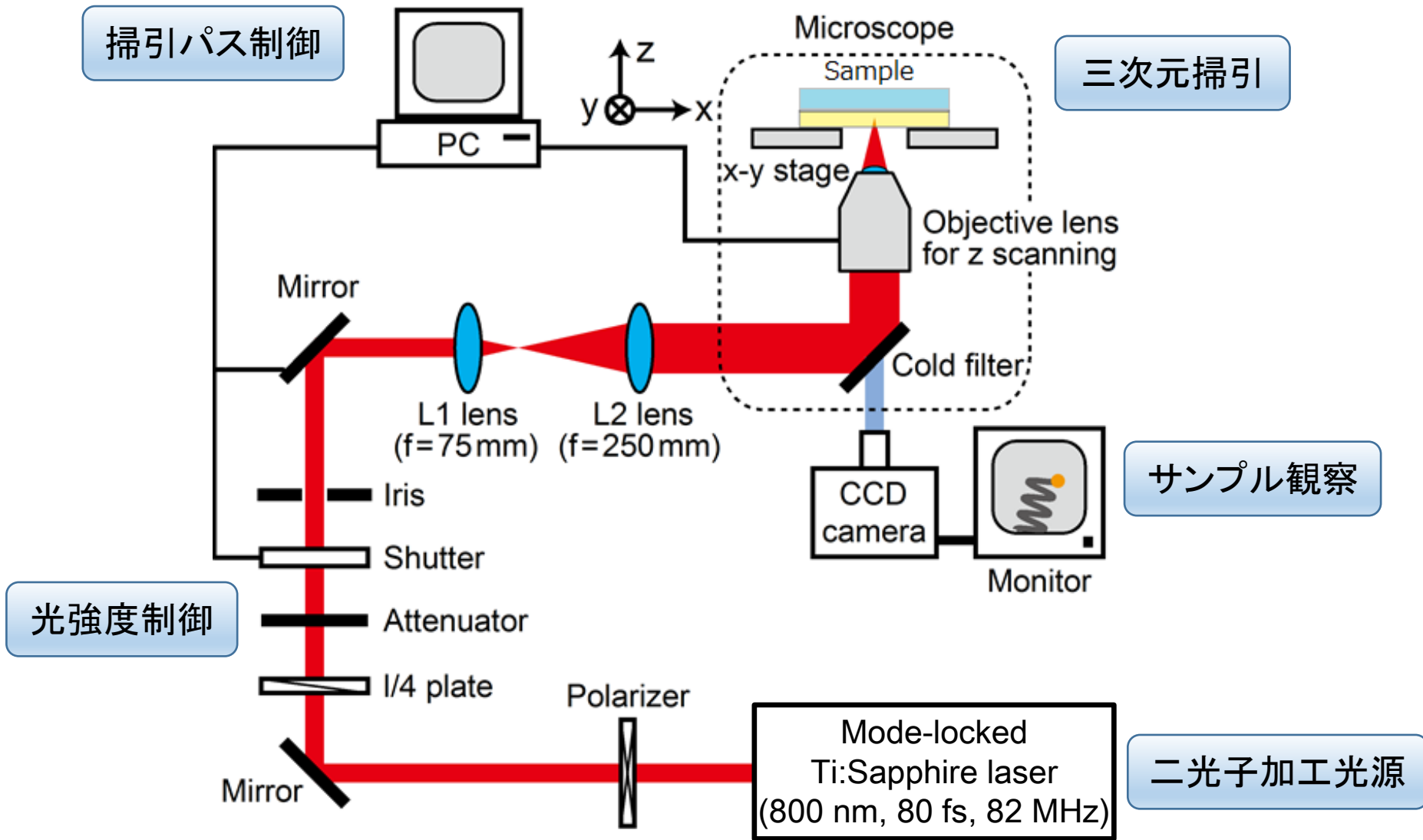
赤外光  
800 nm



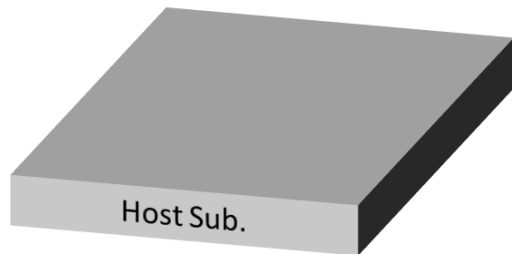
同時に二つの赤外光光子が吸収される  
発生確率が光強度の自乗に比例



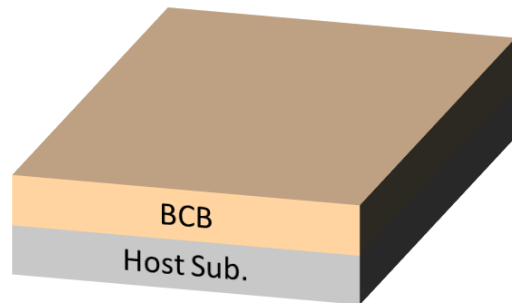
紫外線硬化樹脂により導波路を作製



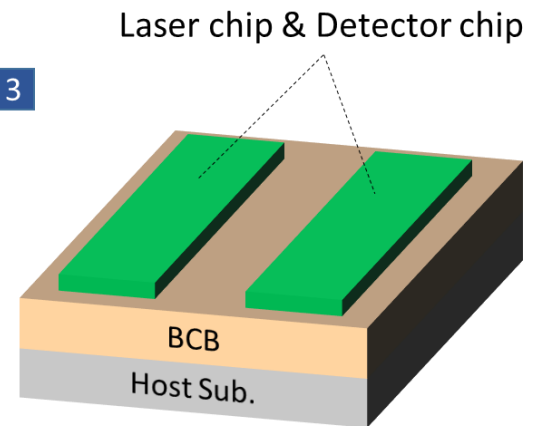
1



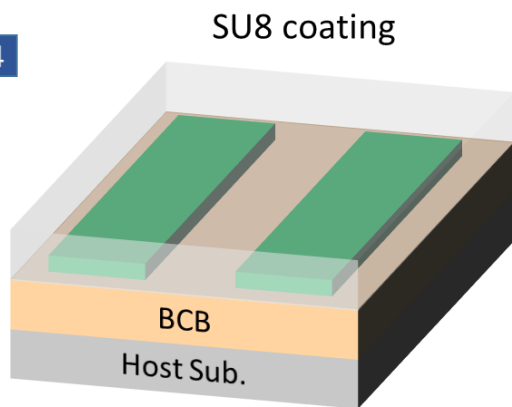
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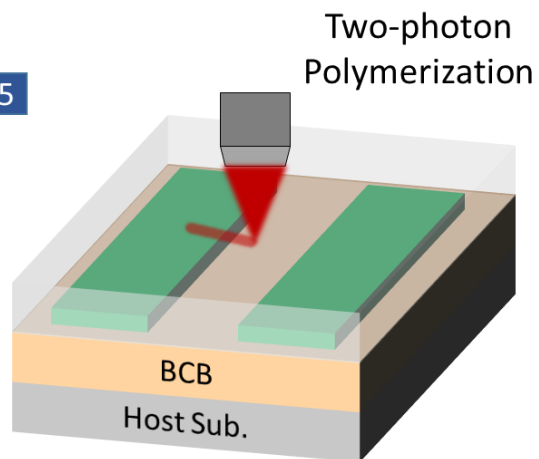
3



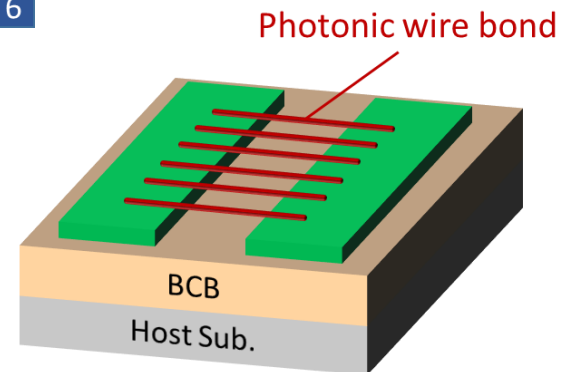
4



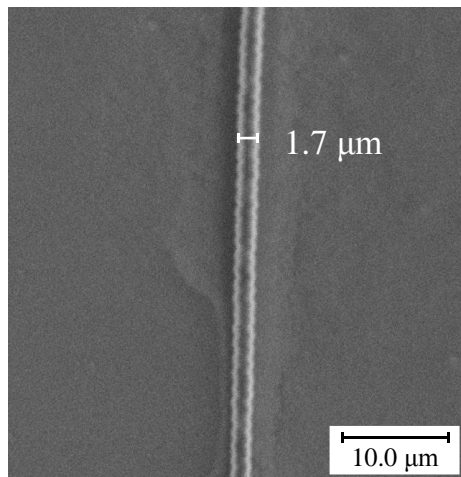
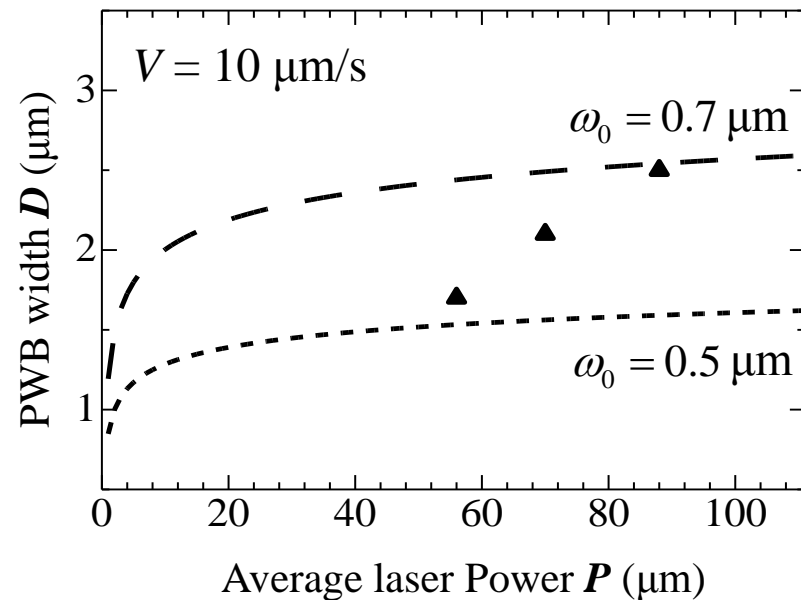
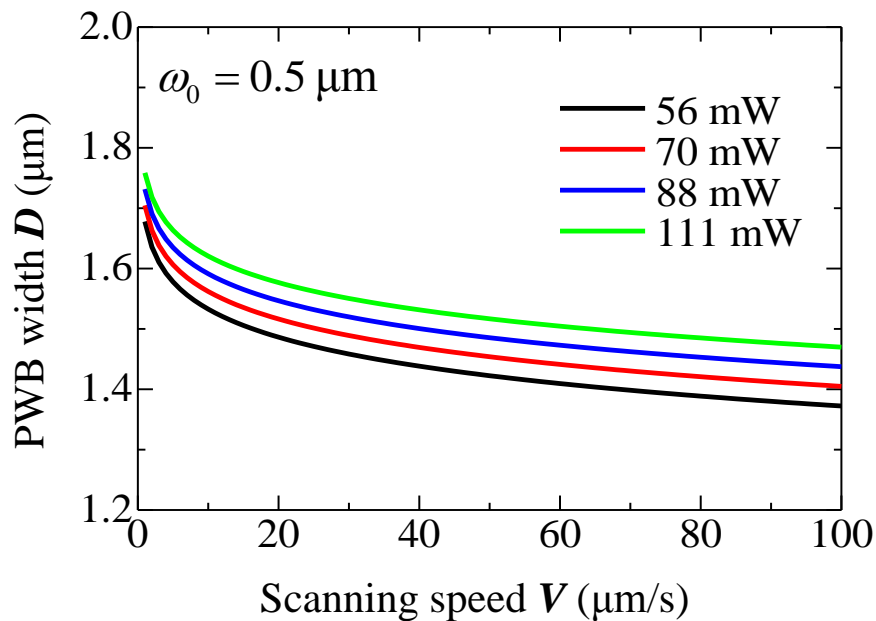
5



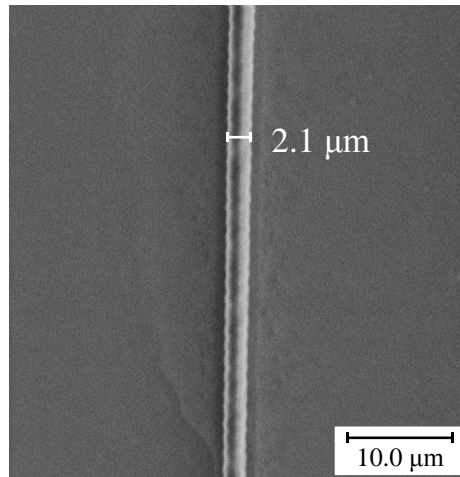
6



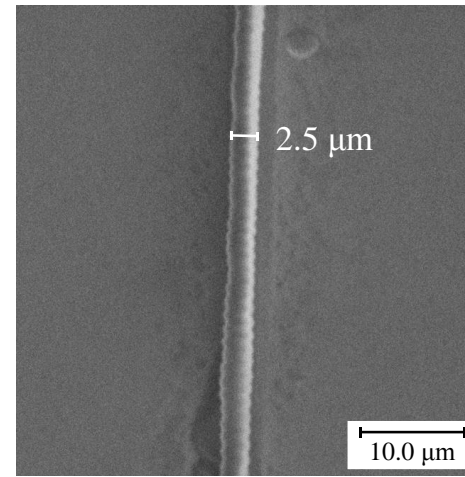




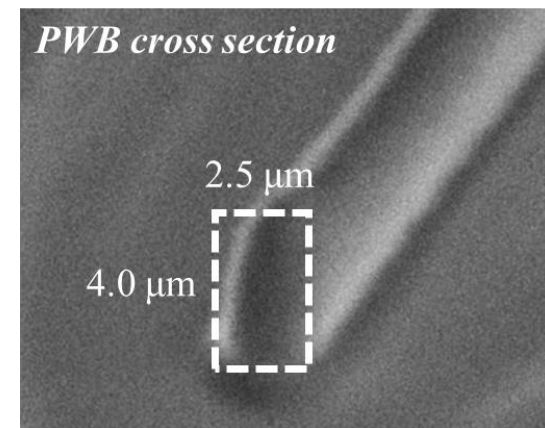
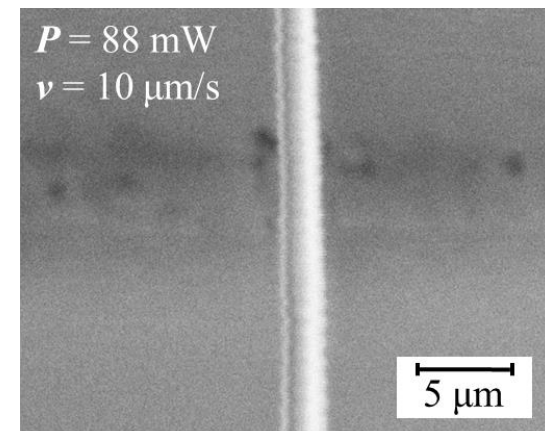
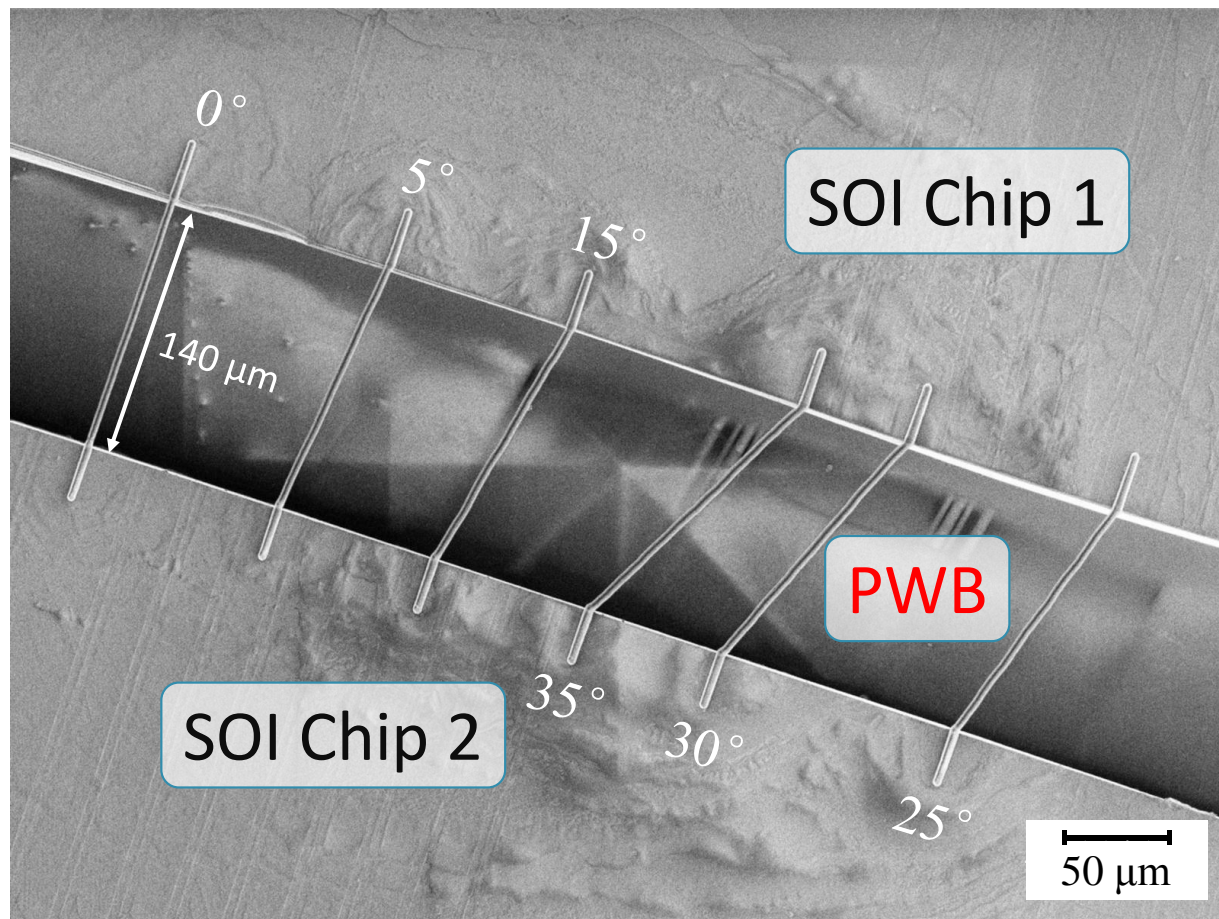
$P = 56 \text{ mW}$



$P = 70 \text{ mW}$

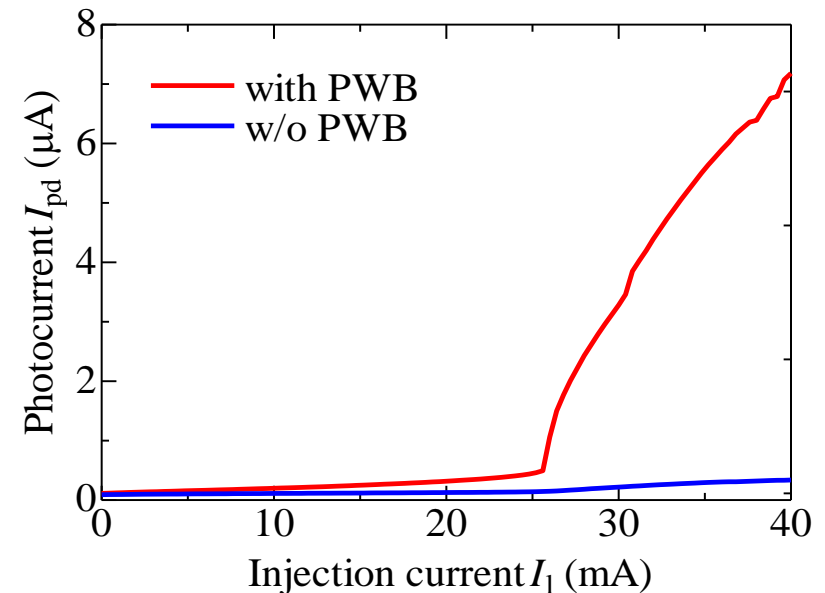
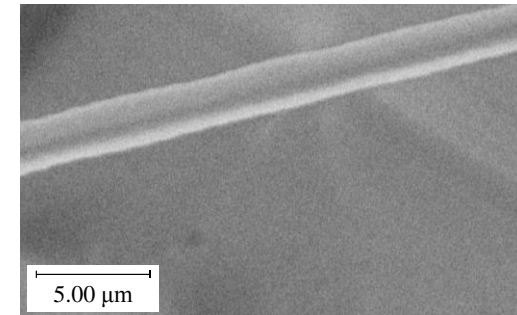
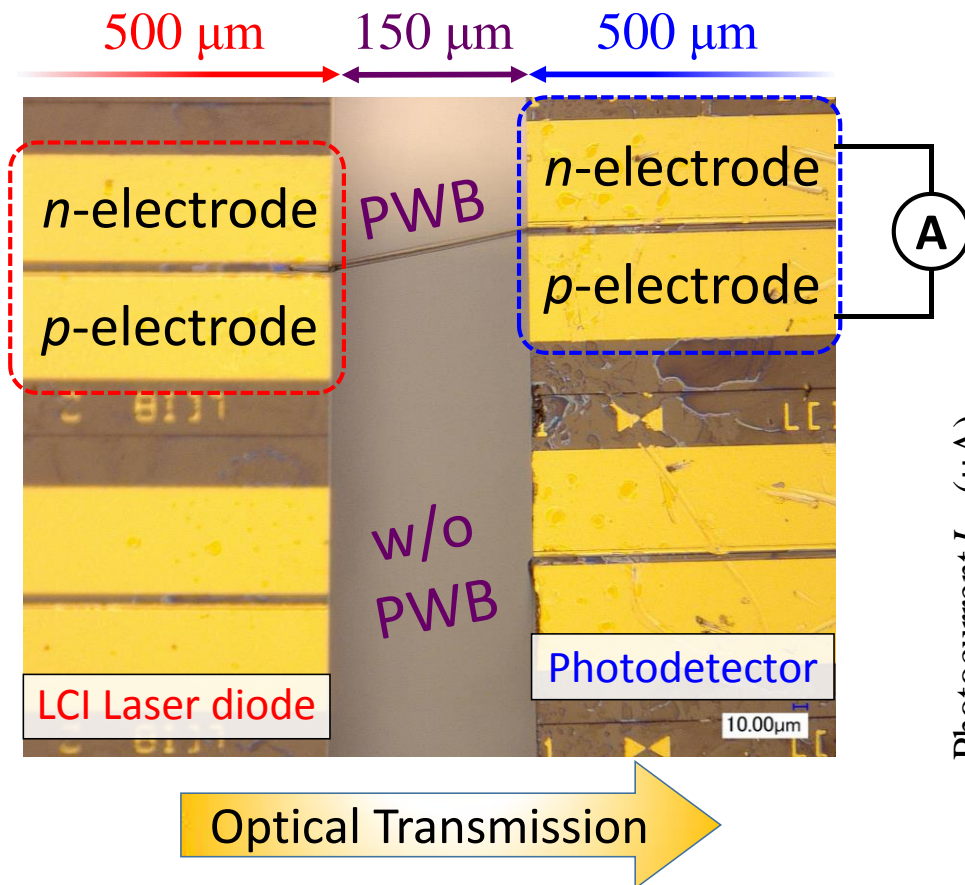


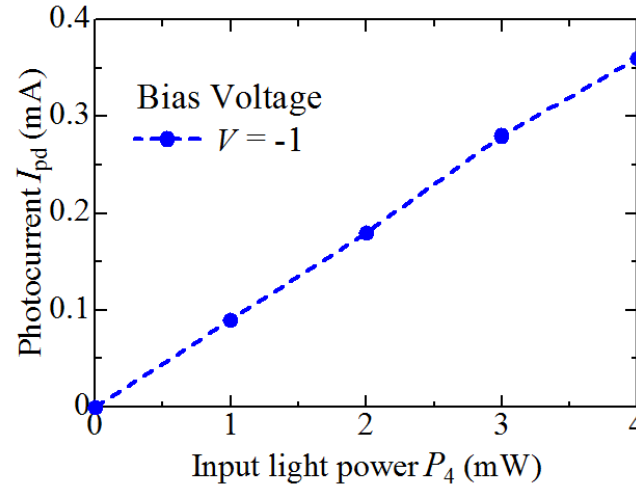
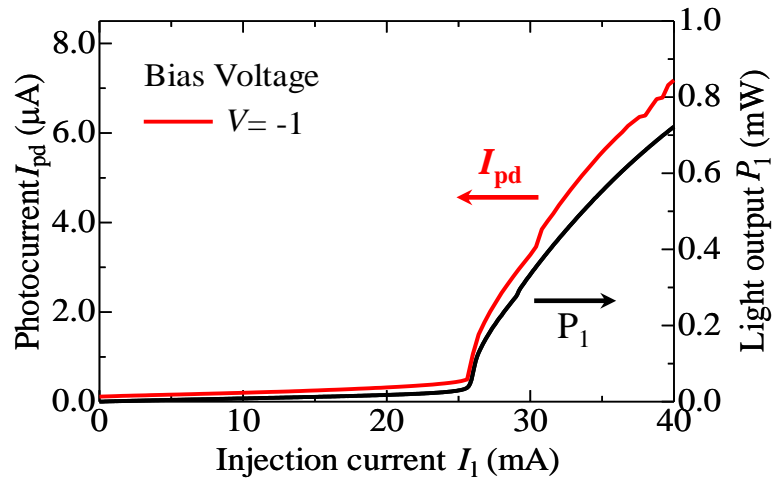
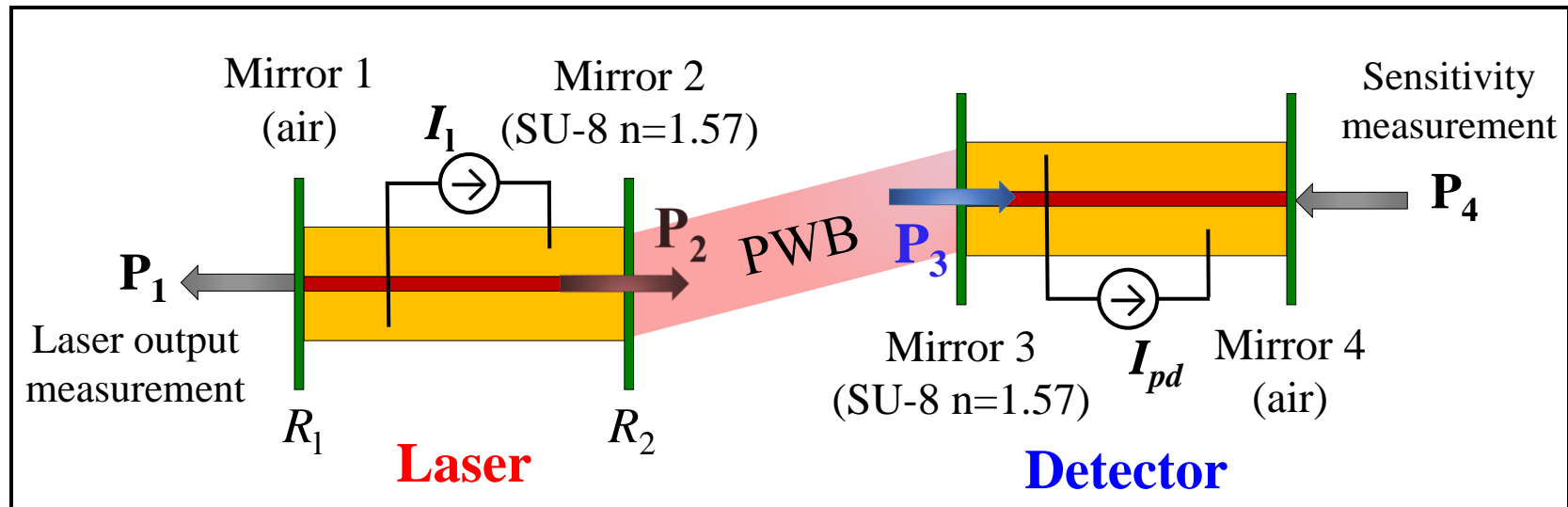
$P = 88 \text{ mW}$



# Si上光源と受光器のPWB接続(1)

- PWB/活性層中心位置ずれ数100 nm範囲内で高精度に作製
- PWBを固定させるため20  $\mu\text{m}$ 程度ストライプ上にもレーザ掃引



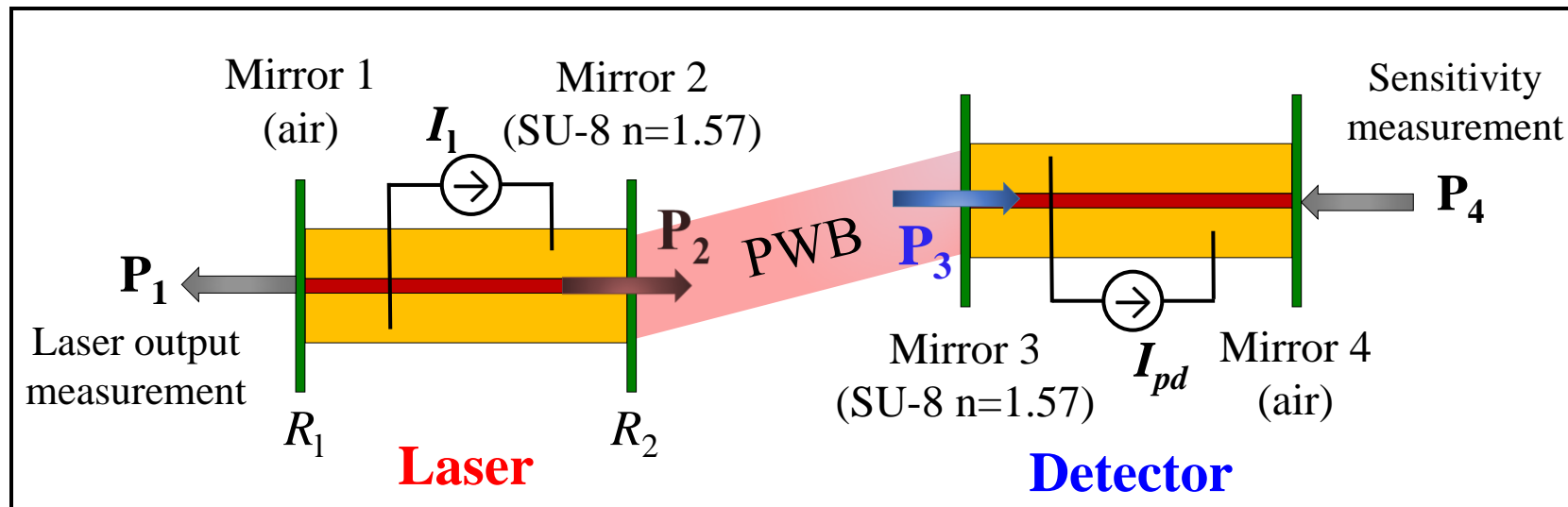


Photodetection  
Sensitivity  $\eta_{pd}$

$$\frac{\Delta I_{pd}}{\Delta P_4} = 0.09 \text{ A/W}$$

光源の閾値電流と受光器の立ち上がり電流が一致





$$P_2 = \frac{(1-R_2)\sqrt{R_1}}{(1-R_1)\sqrt{R_2}} P_1 \approx 2P_1$$

$$P_3 = \frac{I_{pd}}{\eta_{pd}}$$

$$\text{PWBによる損失} = 10 \log \frac{P_3}{P_2} \approx 10 \log \frac{I_{pd}/\eta_{pd}}{2P_1(I_l)} \approx 10 \text{dB}$$

10dB程度の損失を推定

# フォトニックワイアボンディングによる異種材料光素子集積

## 結合損失の理論的検討

- メンブレンレーザ/PWB最大結合効率: 52% (-2.8dB)
- LCIレーザ/PWB最大結合効率: 70% (-1.6dB)

## PWBの作製法の確立及び光伝送の実測

- PWB作製条件: レーザパワー88 mW & NA 0.95
- PWB接続によるレーザ・ディテクタ間光伝送を確認