Recent Progress in Photonic Crystal Devices

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Topics

**PC Nanolaser**
- RT CW lasing in ultrasmall nanocavity
- Purcell effect and thresholdless behavior
- Active and passive integration
- Application to refractive index sensing

**PC Slowlight waveguide**
- Dispersion-compensated slowlight
- Zero-dispersion slowlight

**PC Negative refractive optics**
- Lens and prism effects
- Application to compact demultiplexer
A thin membrane with airholes

Light is confined by TIR and PBG effect occurs in the plane

Easily fabricated into SOI, III-V with < 5nm roughness

Widely applied for lasers, waveguides, dense photonic integration, etc.
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Point hift PC anolaser

An laser consisting of only two point shift  o a i et al  EL 41

RT CW lasing first achieved in nanolaser  o a i et al  OE 15

Fabricated by  CP  de et al  JJAP 45  L

World's smallest  \( V_m \)  \( \lambda n \) evaluated  o a i et al  APL 88
Purcell effect in PC anocavity

aba et al *APL* 85

rate enhanced by factor

\[
\frac{\Gamma_r \lambda}{\pi n V_m \Delta \lambda}
\]

\(\Delta \lambda\) Cavity linewidth

homog broadening

or

RT

\(\Gamma_r\) Photoluminescence rate enhanced by factor

\(\lambda\) Resonance wavelength

\(V_m\) Mode volume

\(\Delta \lambda\) Cavity linewidth

RT

aba et al *APL* 85

oa i et al *OE* 15

x – enhancement expected for various materials including i etc

Thresholdless lasing expected

\(RT\) Room temperature

\(P_{irr}\) Irradiance

\(P_{th}\) Threshold power

\(\lambda\) Resonance wavelength

\(\lambda_{mode}\) Mode wavelength

Wafer

PC w o cavity

Point-shift nanocavity

\(\mu m\) Micrometer
PC laser and waveguide integrated by butt oint C D regrowth process

Estimated for total output $\eta_d$
Coupling of laser and waveguide enhanced by optimizing distance and direction

Integration of PC and laser with Waveguide

Graph showing detected power by fiber versus effective pump power.
witching behavior by Resonant Pumping

or Pump or Laser

Efficient selective excitation of nanocavity
Applicable to wavelength converter bistable device etc
Index sensitivity in PC anolaser

Potential detection limit of wavelength nm

Lasing wavelength m

Normalised intensity au

Lasing wavelength λ m

Ax sensitivity nm R

Environmental index n_{env}

Spectral W pm

Resolution limit sensitivity of nm R

Potential detection limit of R
Large index sensitivity of \( \Delta n \) nm using TuC p-pectrometer-less sensing from \( P \) using laser array and \( P \).
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PC low Light Waveguide

after aba et al \textit{EL 5}

- Asy fabrication on wafer etc
- Lossless guided mode exhibiting slow light at bandedge with narrow bandwidth and large D

\begin{itemize}
  \item Transmission\newline
  \item Photonic edge\newline
  \item Wavelength\newline
  \item Group index\newline
  \item Transmission -P resonance\newline
  \item Rom modulation phase shift\newline
\end{itemize}

\begin{itemize}
  \item Channel\newline
  \item Air\newline
\end{itemize}
Dispersion-free Widband low Light

Dispersion-Compensated low Light

Zero-Dispersion low Light
Low velocity Low Dispersion

Spatially dispersed
Spatially compressed

Partially dispersed
Partially compressed
Smooth Delay by Coupled Waveguides

(Mori and Baba, *Opt. Express* 13, 9398 (2005))
Effective Delay in Low Light Pulse

**Diagram:**
- **ode-Loc ed iber Laser**
- **Lensed iber**
- **PCCW**
- **Auto-correlator**
- **D A**
- **Δ Mechanical**
- **Wavelength λ μm**
- **Intensity a u**
- **Delay Time Δ ps**
- **Delay Time Δ ps**
- **Wavelength λ μm**
Dispersion-Free Wideband low Light

Dispersion-Compensated low Light

Zero-Dispersion low Light

Spatially dispersed

Spatially compressed
LD Characteristics in PC Waveguides

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**a ai aba et al.**

*EEE LEO Ann Th - patented in*

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![Image of Air Light Cone and line plot](image.png)

- **Air Light Cone**
- straight and
- \[ \omega / 2\pi \]
- \[ \text{lab ode} \]
- \[ [2\pi/\]
Observation of LD Characteristics

Transmission

$\omega / 2\pi$

Calc

$n_g$

Calc

$\pi$

$\omega / 2\pi$
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Functions Predicted from Dispersion Surfaces

(after Kosaka et al., *PRB 58*, 10096 (1998))

1. Isotropic Propagation
2. Super lens
3. Super-Collimation
4. Super prism
5. Slow light
Negative Refraction by Optimized Interfaces

(Baba et al., *Opt. Express* 12 (2004) 4608)

\[ \frac{a}{\lambda} = \begin{array}{ccccc}
0.275 & 0.281 & 0.287 & 0.293 & 0.299 \\
\end{array} \]
Observation of Negative Refraction

Deflection Angle $\theta$

Wavelength $\lambda$

PC

Input

Plot  Experiment  Line  DTD
Light Focusing in PC Superlens

(Matsumoto, et al. OL 31, 2776 (2006))

\[ L = 1.305 \, \mu m \]

\[ \lambda = 0.5 \mu m \]

PC slab superlens

Intensity [a.u.]

Position [\mu m]
Unique Focusing of PC Superlens

Dispersion Surface

\[ a/\lambda = 0.295 \]

RefRACTIVE Lens

Super-Lens

- Real image formation by flat lens (virtual image by curved lens)
- Compact total system due to very short focal length
- Applications to compact parallel optical coupler, demultiplexer, image system, etc.
Applications of superlens

Parallel optical coupler
atsumoto et al E.L W

Compact demultiplexer
atsumoto et al OE 1

Illustration

PC superprism

Position µm

Intensity a.u.
uperprism and uperlens Demultiplexer

atsumoto et al  APL  1
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