Photonic Integration with Dielectric-Loaded SPP Waveguides

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NFO-10, 2 September 2008, Buenos Aires

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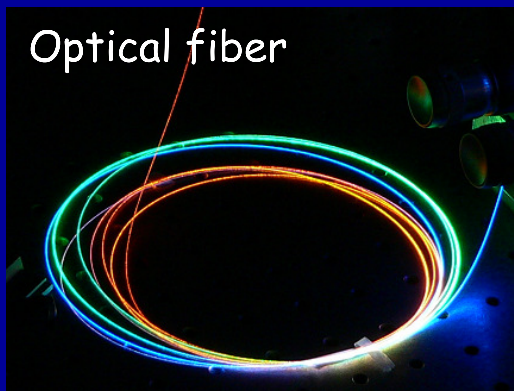
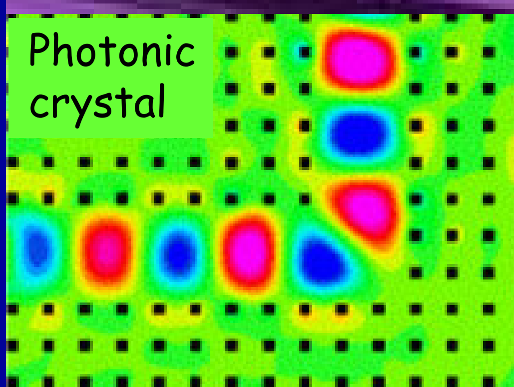
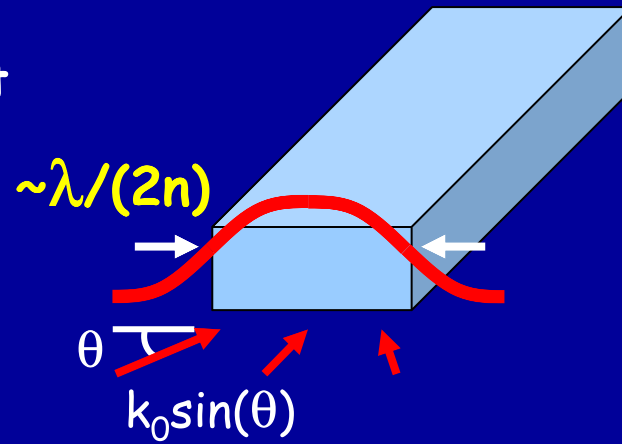
From photonic guiding to integration

Conventional optical waveguides

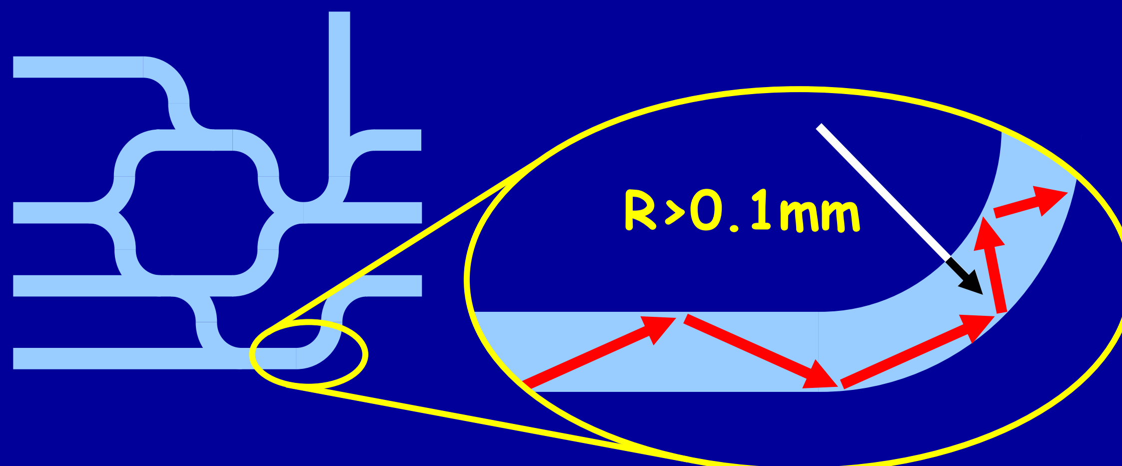




A. Diffraction limit



B. Bend size limit



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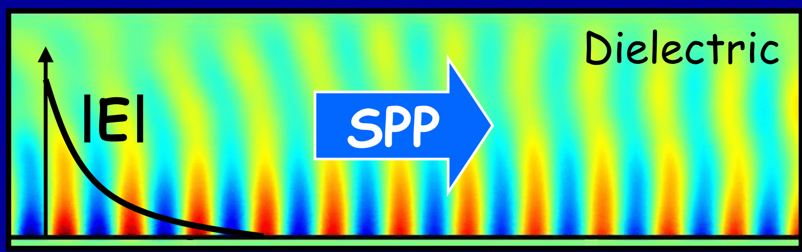
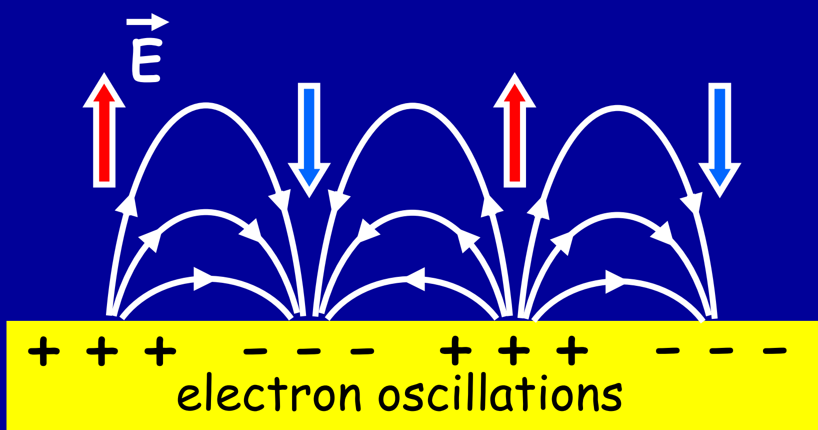
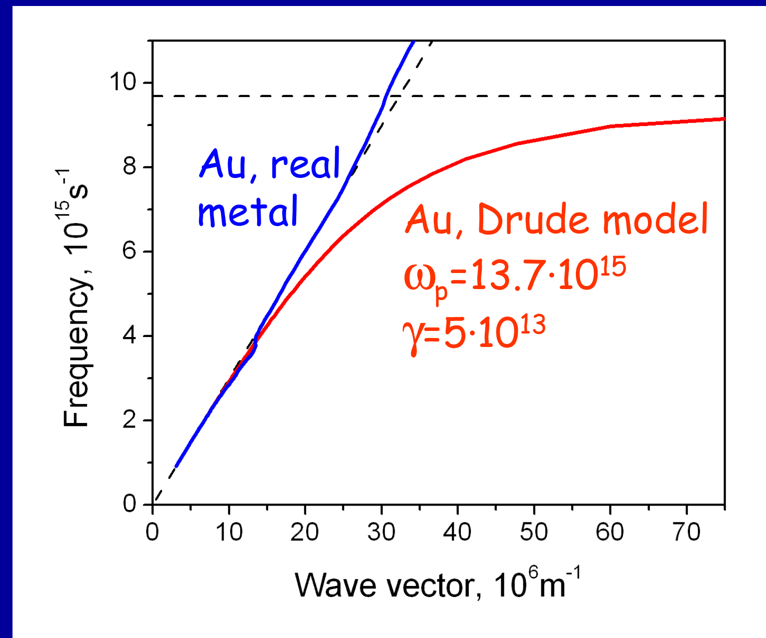
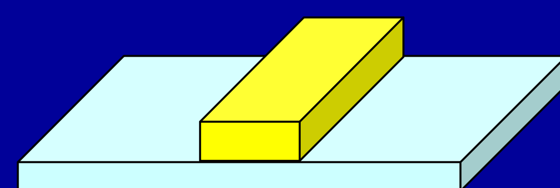
Solution: SPP waves







SPP waveguide



Important length scales:

Wavelength ~> wavelength of light

Propagation length ~ 100 μm

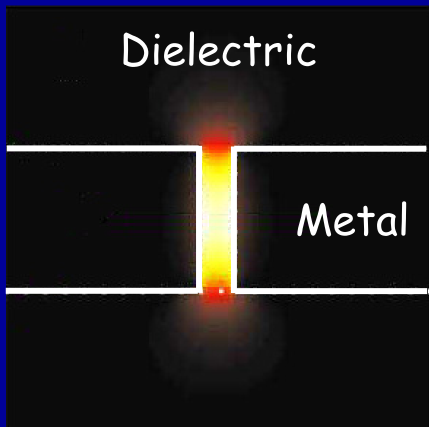
Penetration into:

dielectric ~ 1 mm

metal ~ 10 nm

SPP waveguides: super-high localization

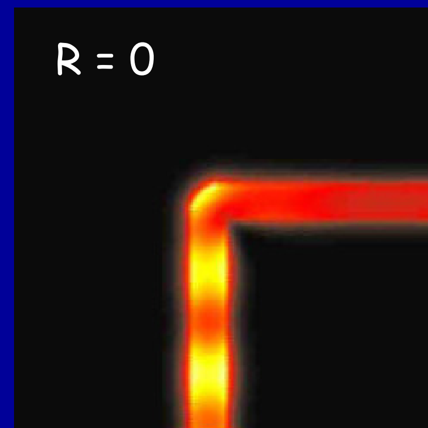
Gap SPP waveguides



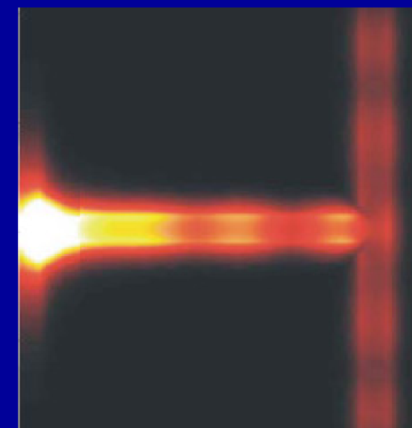
Liu et al., Opt. Exp (2005)

W_{Mode} ~ 25-100nm

L_{Prop} ~ 1-10μm

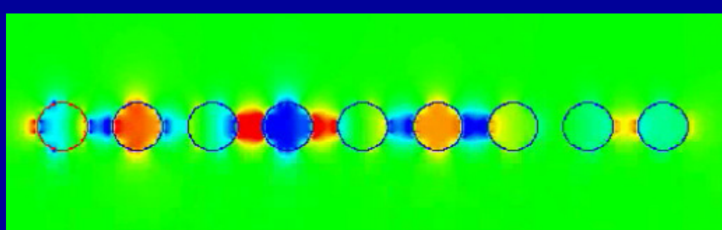


Liu et al., Opt. Exp (2005)



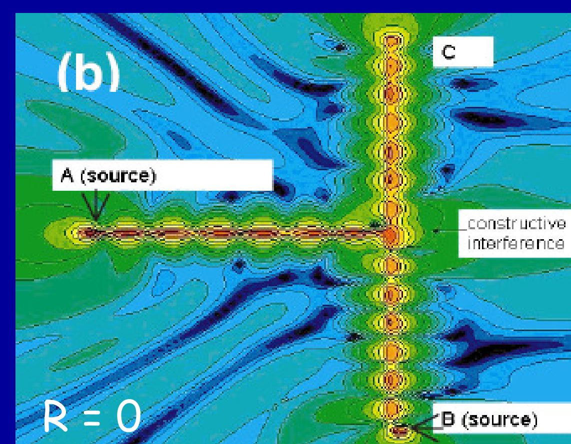
Chen et al., APL (2006)

SPP nanoparticle waveguides



W_{Mode} ~ 100nm

L_{Prop} ~ 1μm



Maier et al., Adv. Mat. (2001)

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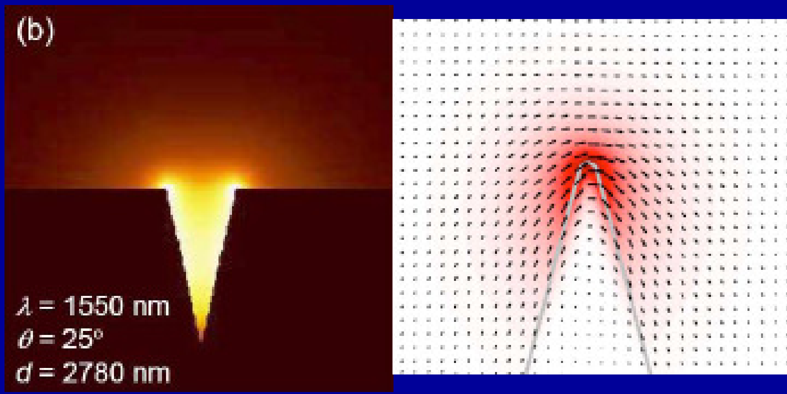
SPP waveguides: super-high localization

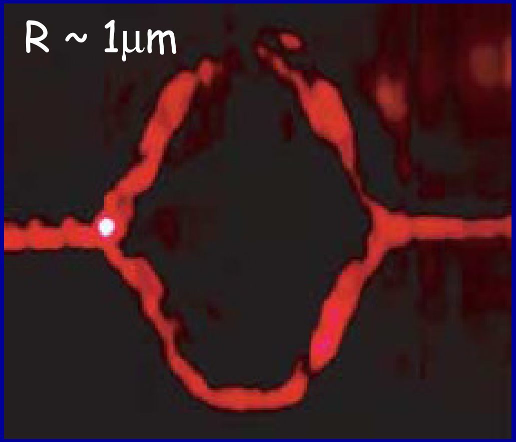
Channel and wedge SPP waveguides



Bozhevolnyi et al., Opt. Exp. (2006), Yan et al., JOSAB (2007)

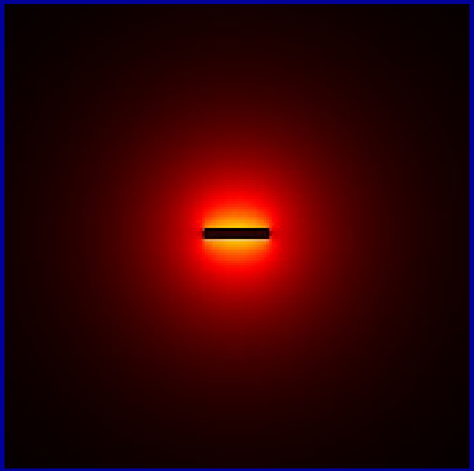
W_{Mode} ~ 1µm

L_{Prop} ~ 50-100µm



Bozhevolnyi et al., Nature (2006)

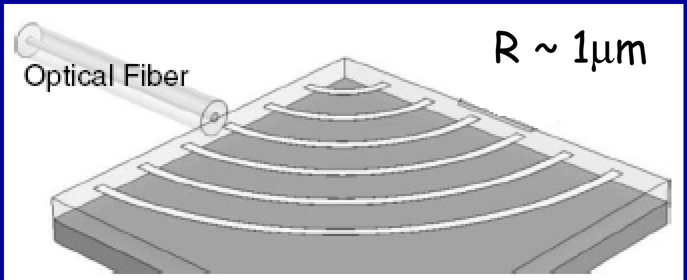
Long range stripe SPP waveguides



Neziad et al., Opt. Exp. (2008)

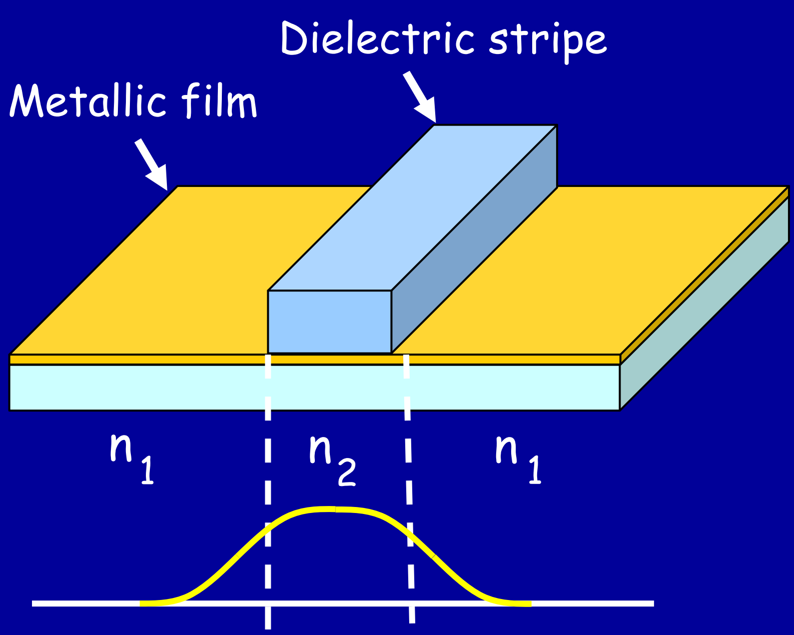
W_{Mode} ~ 3µm

L_{Prop} ~ 3mm



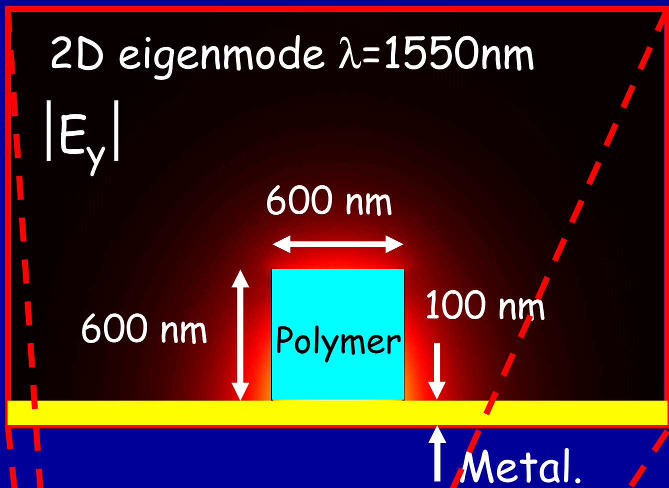
Derigon et al., PRA (2008)

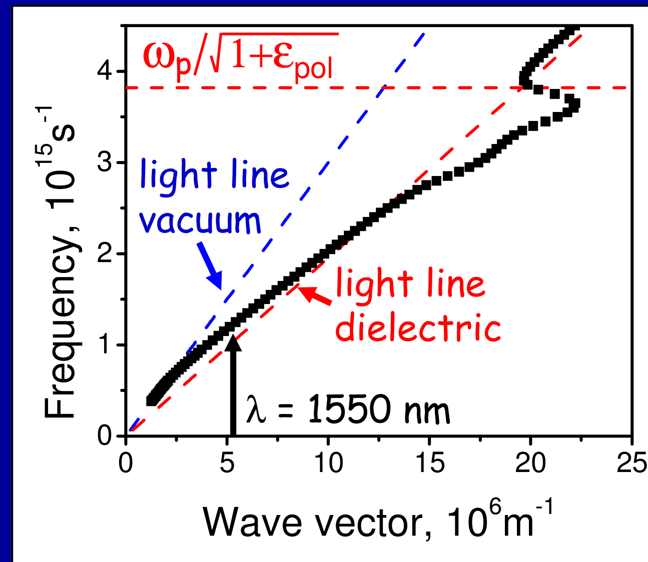
Dielectric-loaded SPP waveguide



- High localization
- High level of integration
- **Thermo-, electro, all-optical functionalities**
- **Easily fabricated and integrated to optoelectronics and electronics**

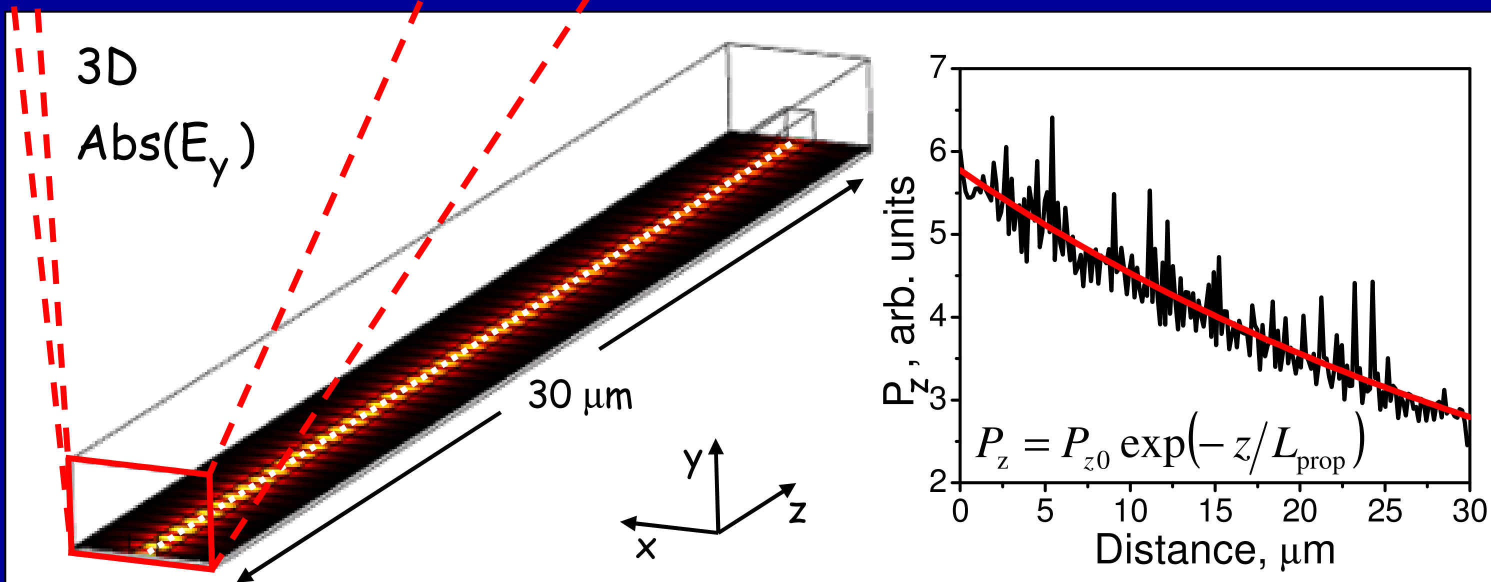
DLSPP Waveguide





λ = 1550 nm
n_{pol} = 1.535
n_{Au} = 0.55 - 11.5i

$Re(n_{eff})$ = 1.289
L_{prop} = 44.2 μm



$Re(n_{eff})$ = 1.289
L_{prop} = 42.3 μm

AV Krasavin and AV Zayats, APL **90**, 211101 (2007)

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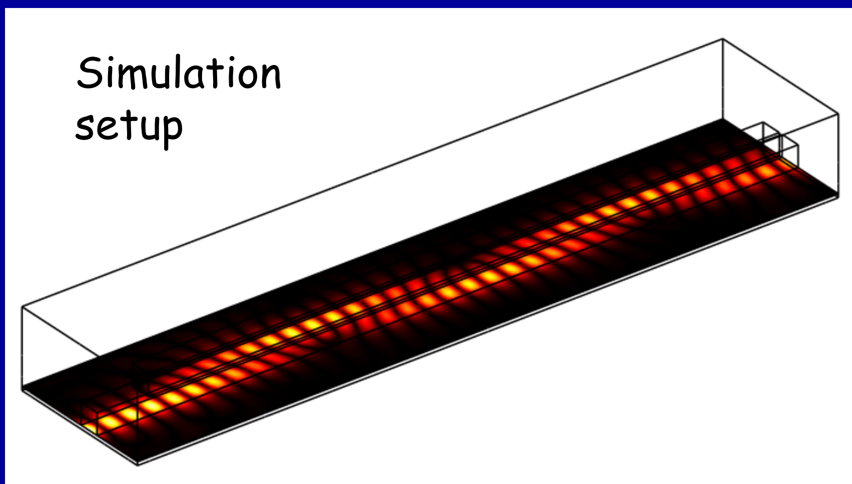
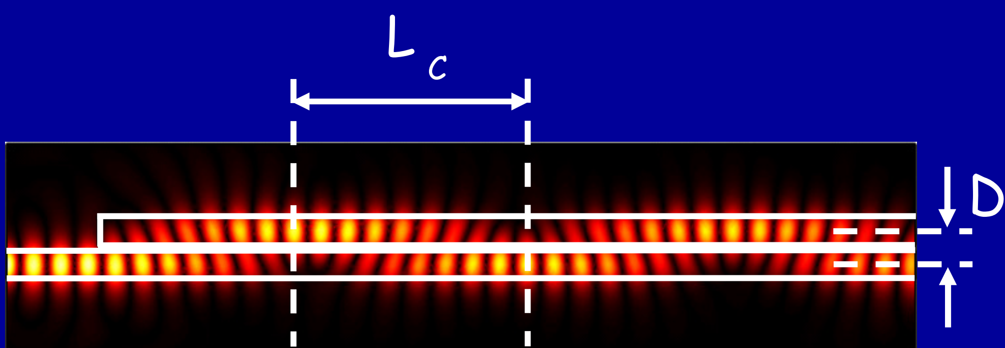
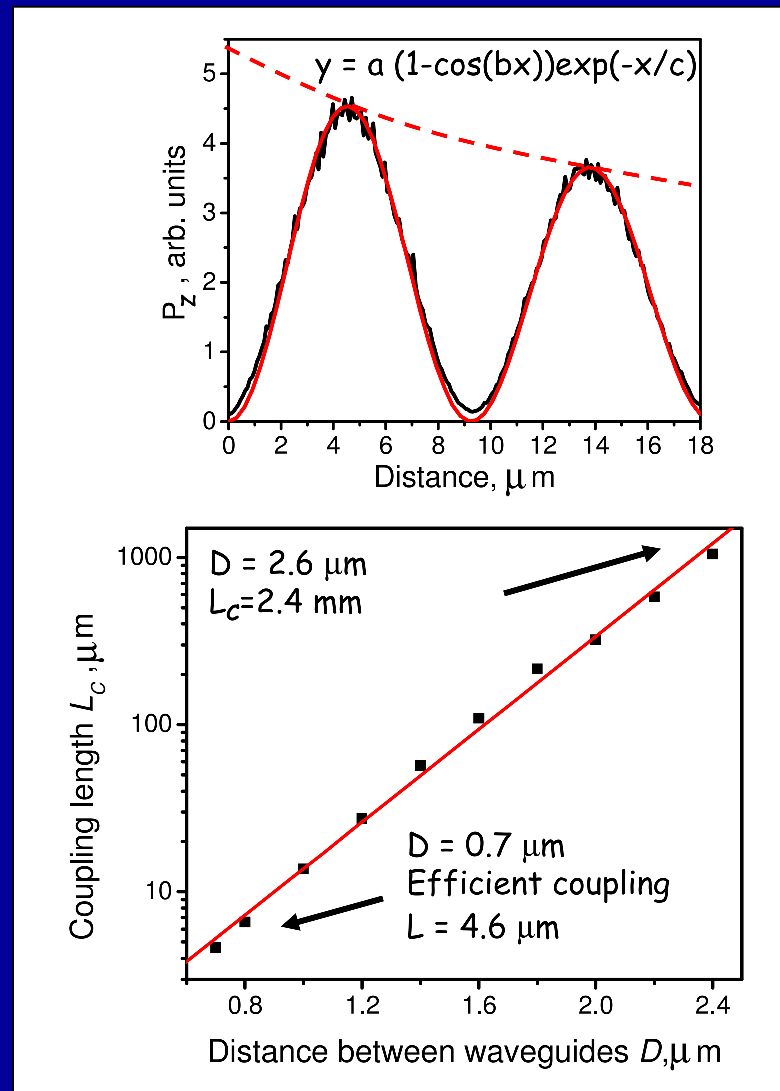
The Ultimate Level of Integration





AV Krasavin and AV Zayats, APL **90**, 211101 (2007)



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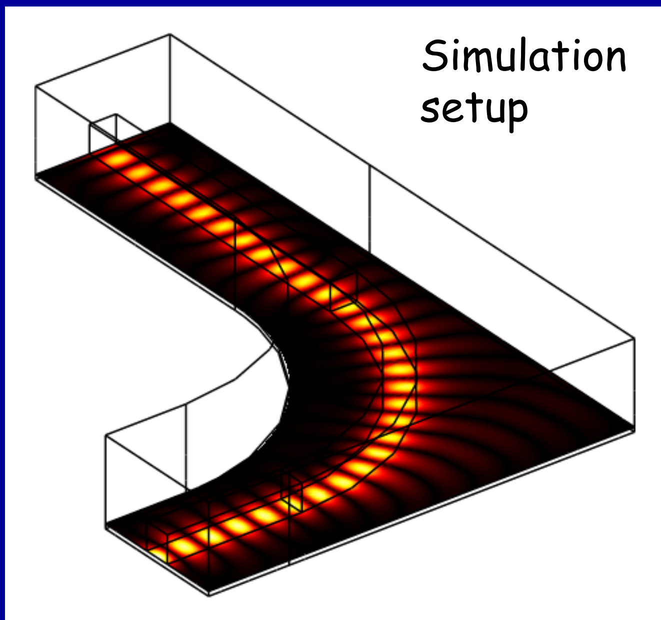
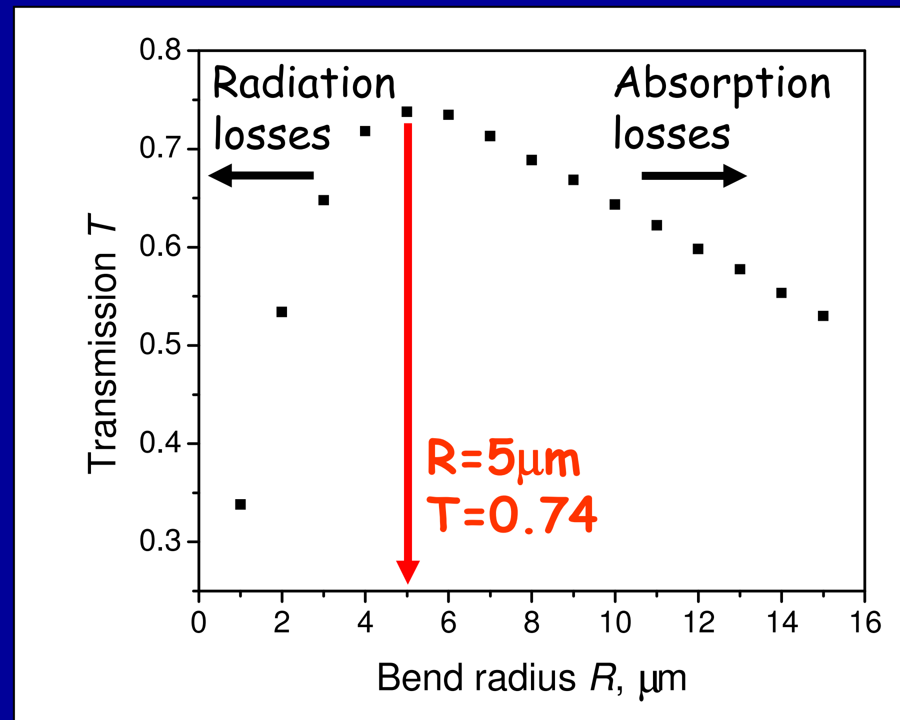
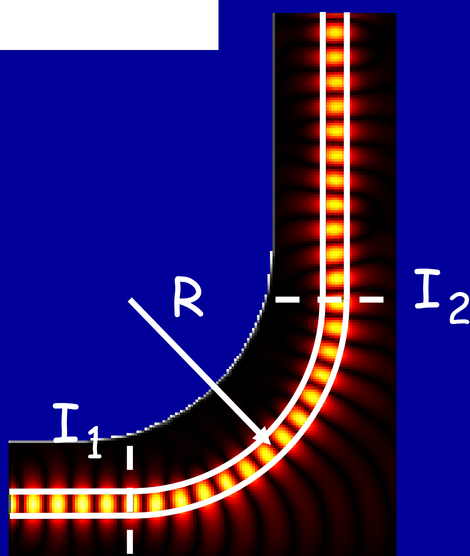
90 Degrees Bend Guiding





Transmission

$$T = \frac{I_1}{I_2}$$



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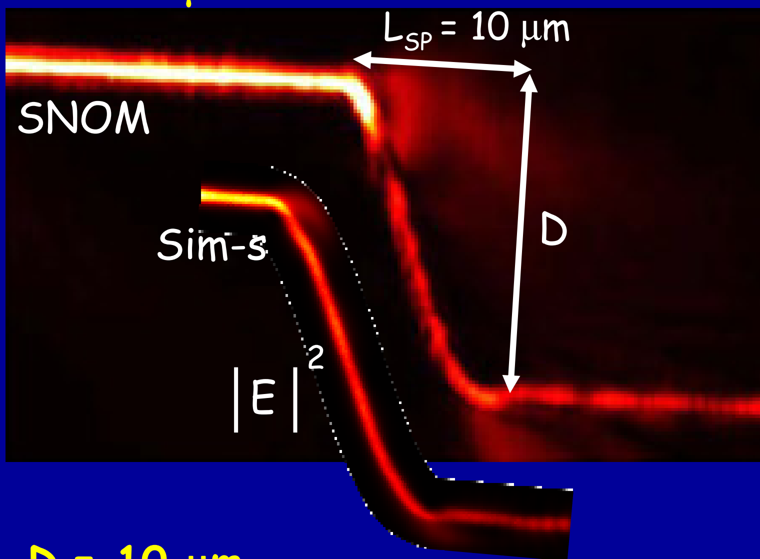
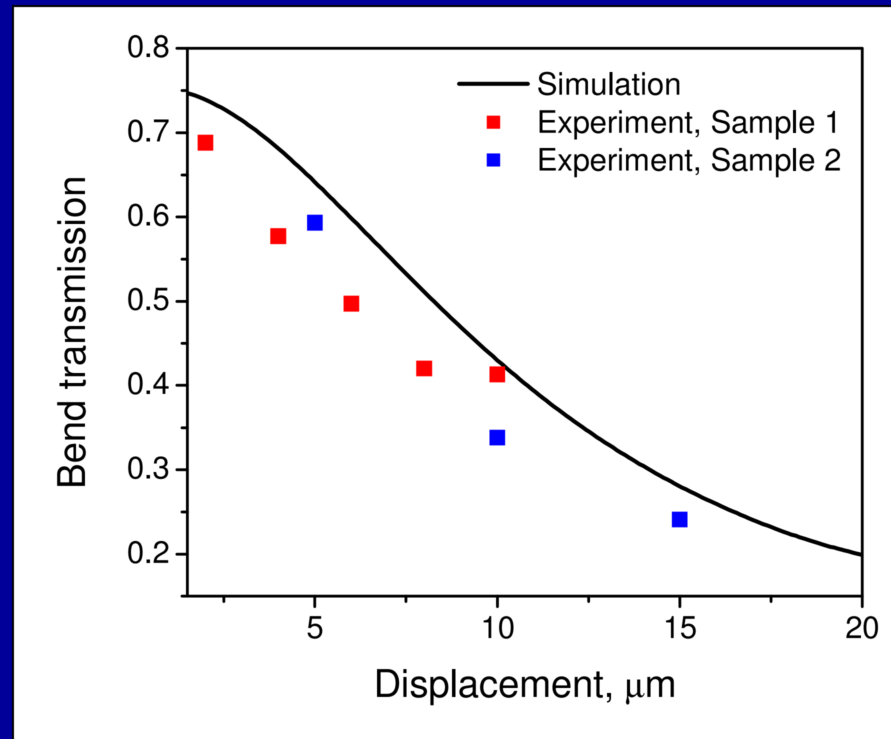
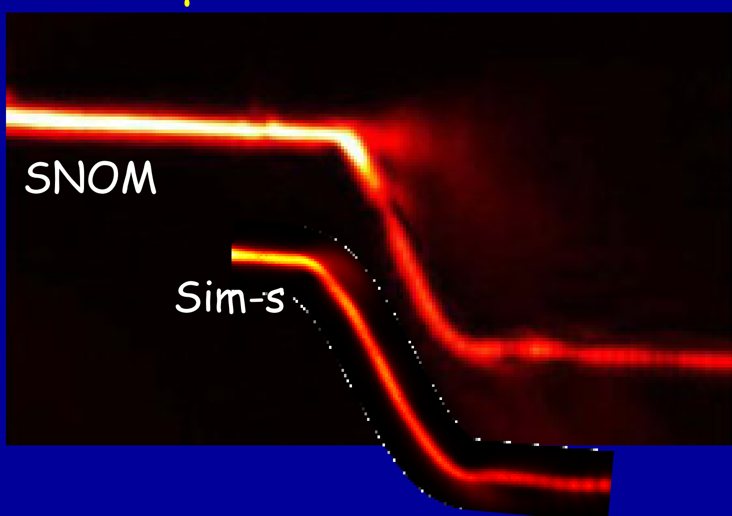
S-bends

D = 15 μm

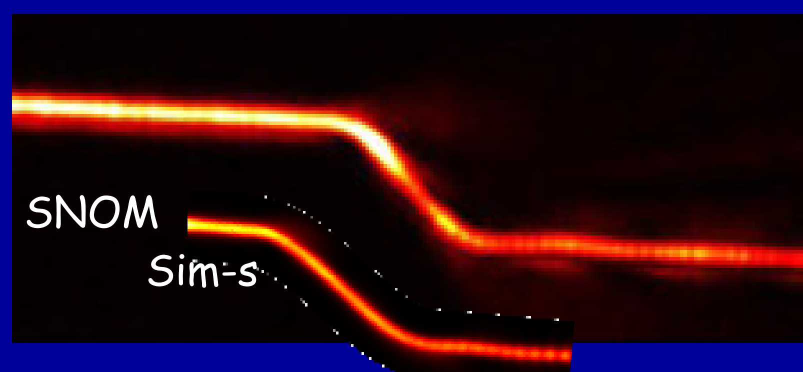




D = 10 μm

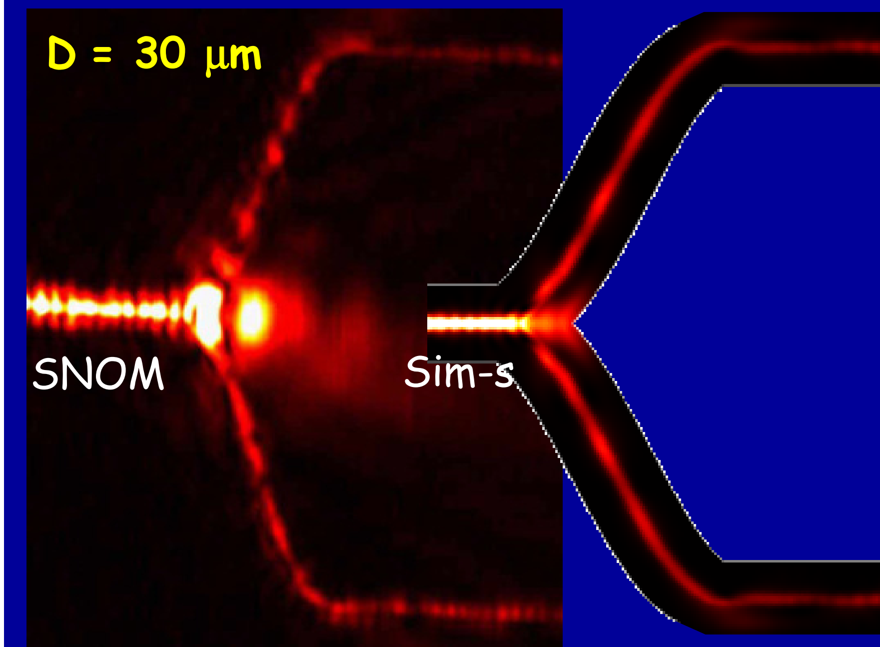


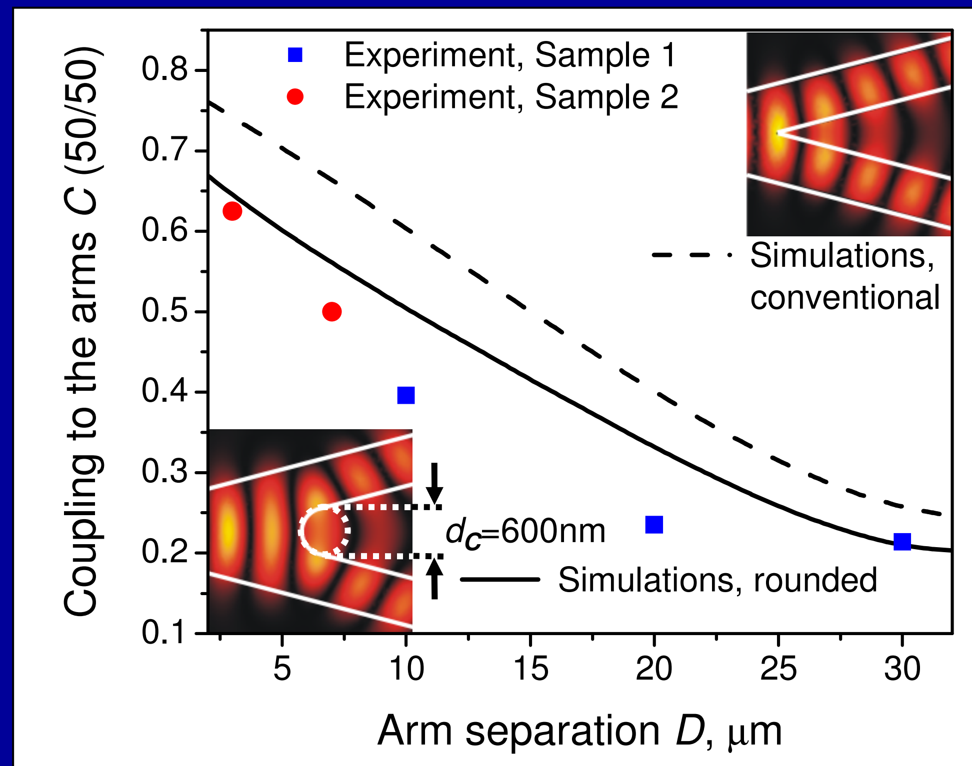
D = 5 μm

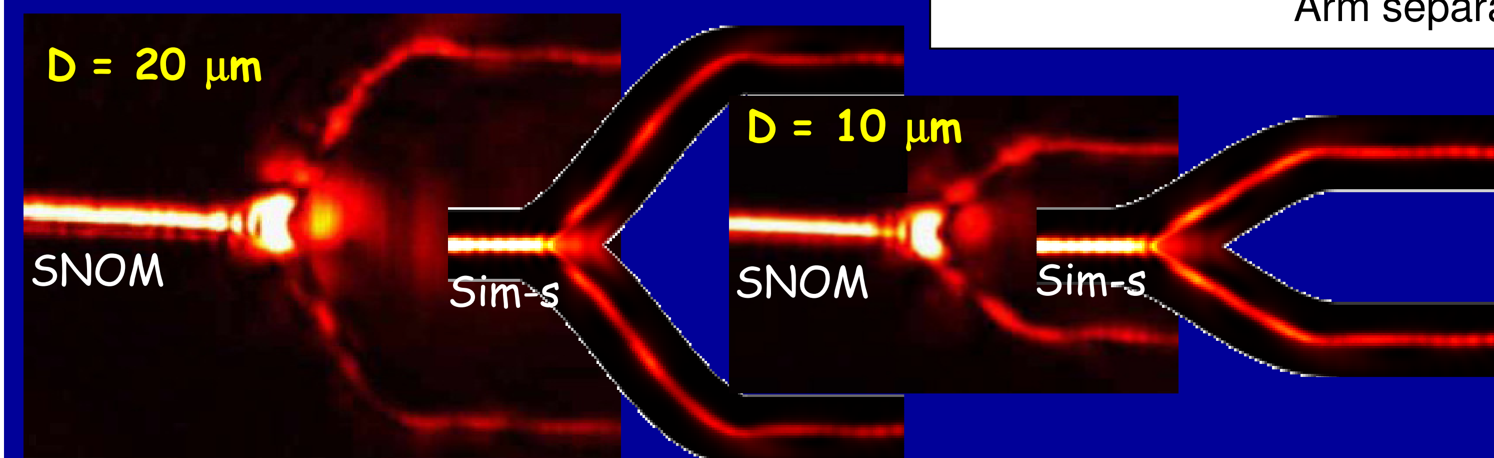


T Holmgaard et el., OE **16**, 13586 (2008), AV Krasavin and AV Zayats, PRB **78**, 045425 (2008)

Splitters







T Holmgaard et el., OE **16**, 13586 (2008), AV Krasavin and AV Zayats, APL 90, 211101 (2007)

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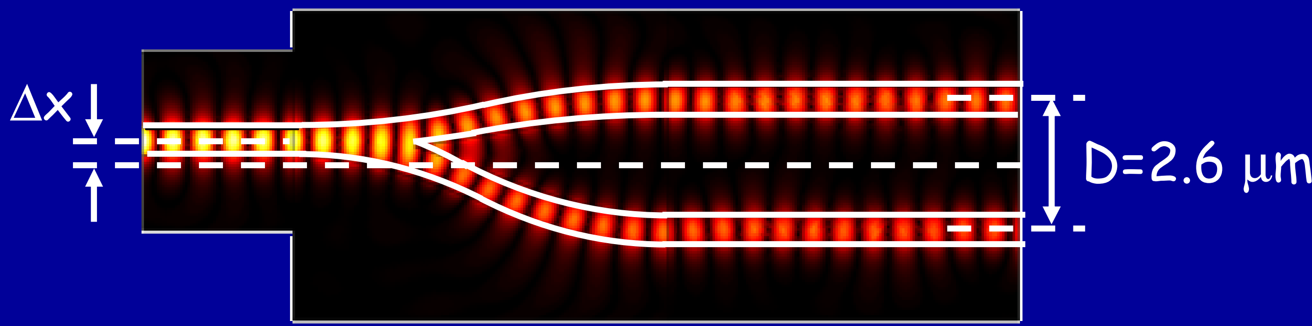
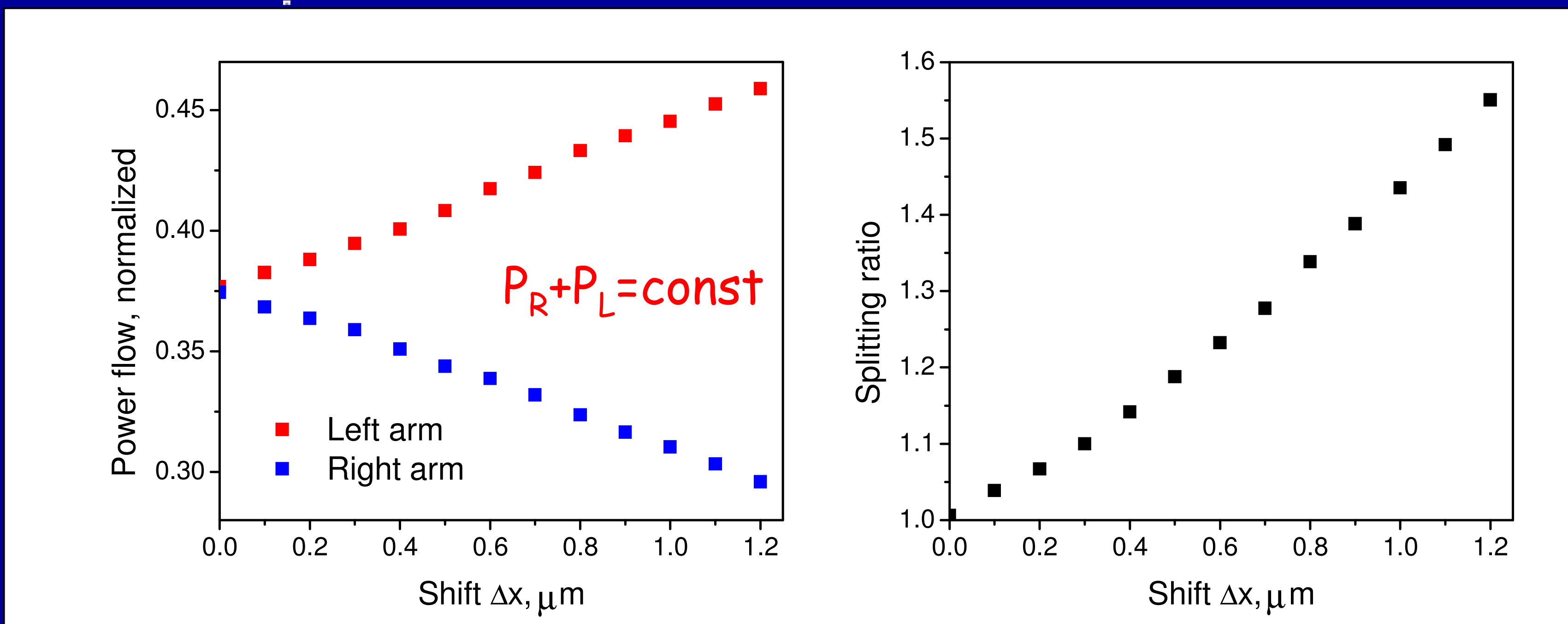
Asymmetric splitter





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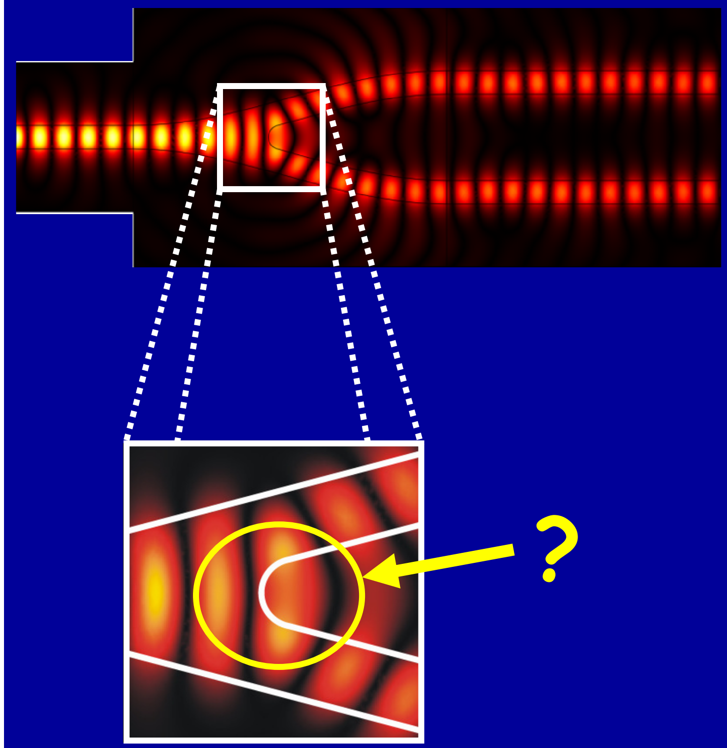
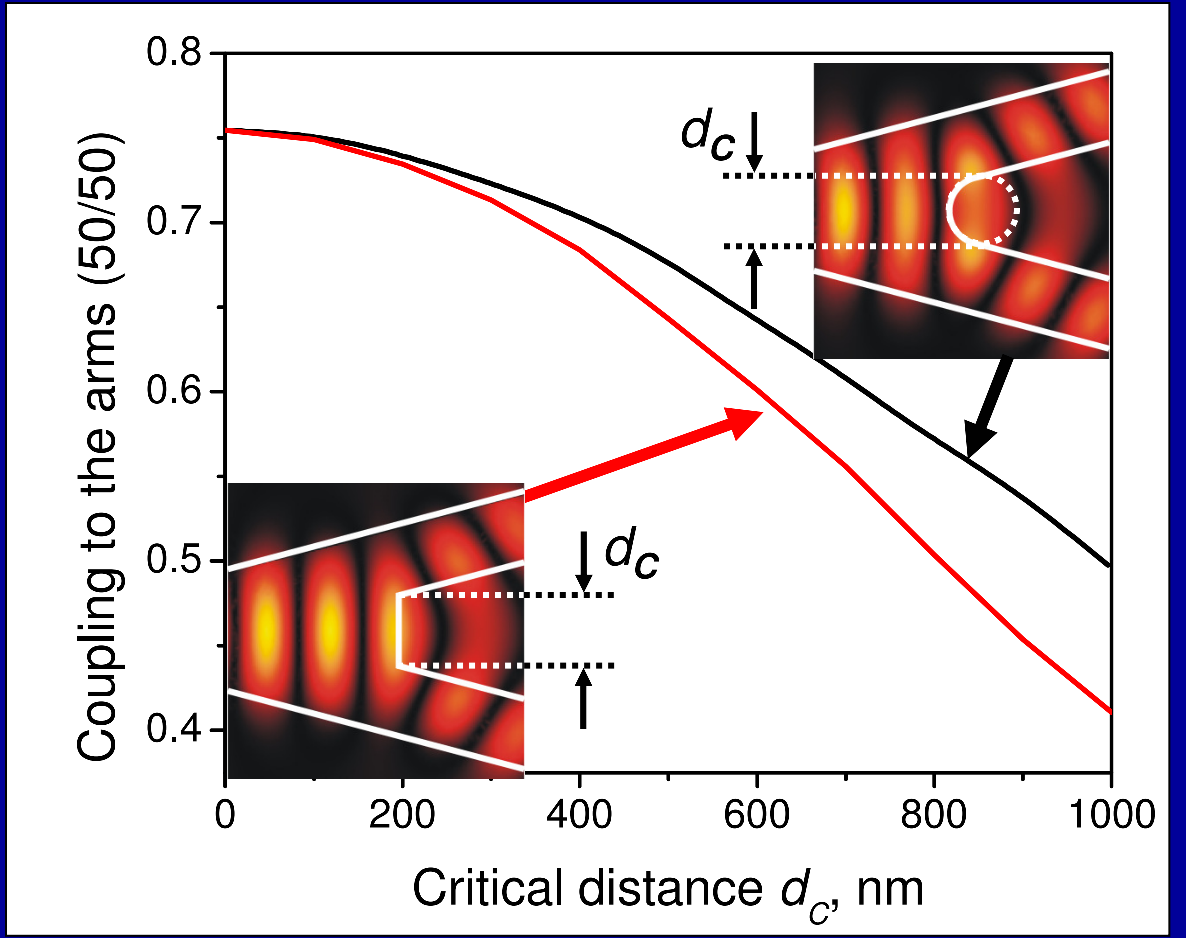
Fabrication: critical distance vs. splitter performance





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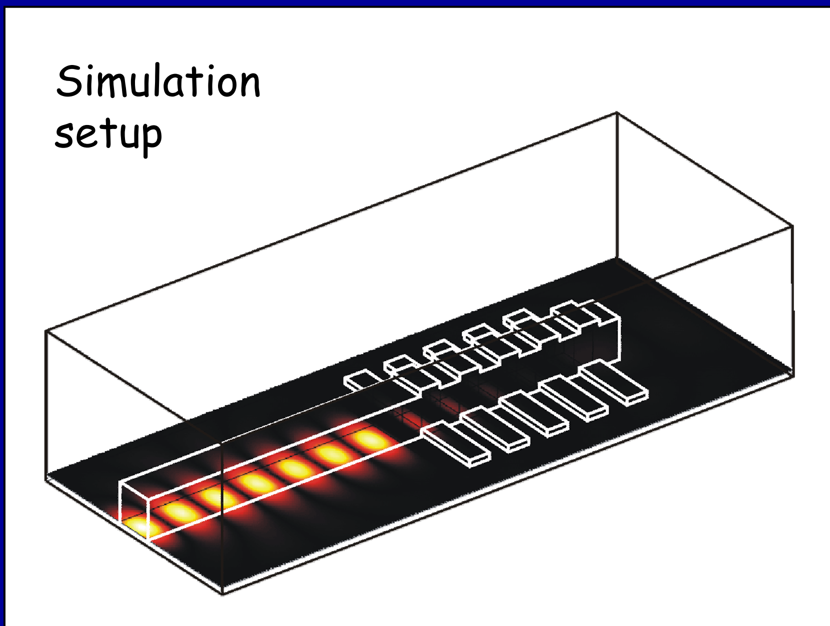
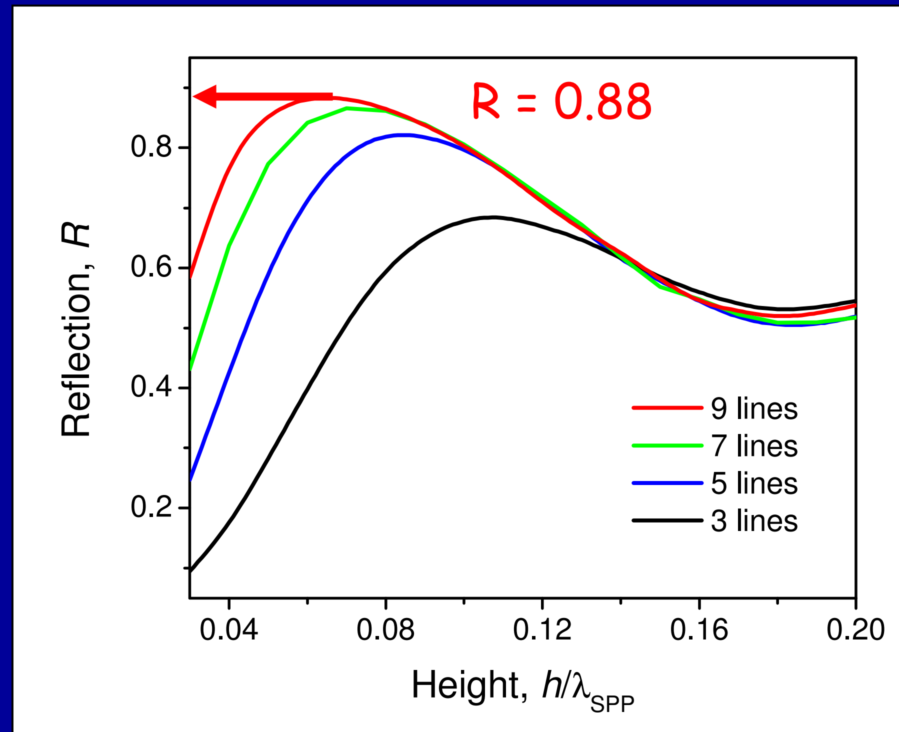
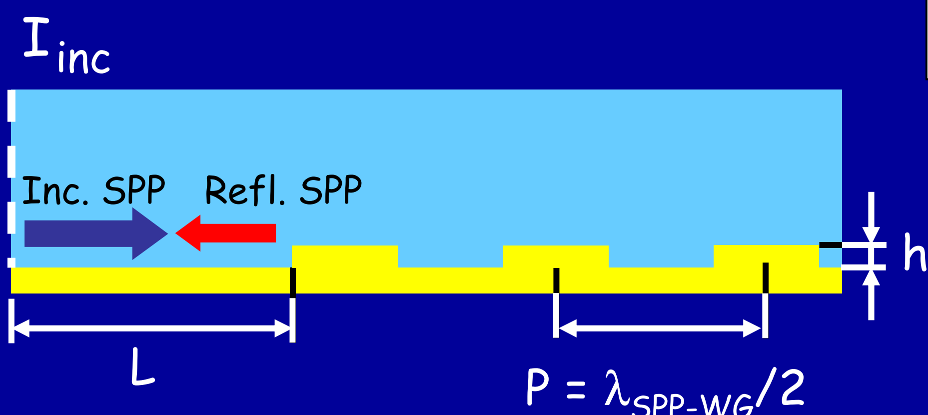
Bragg Reflector







$$R = \frac{I_{inc} - I_{tot}}{\exp(-2L/L_{prop})\, I_{inc}}$$

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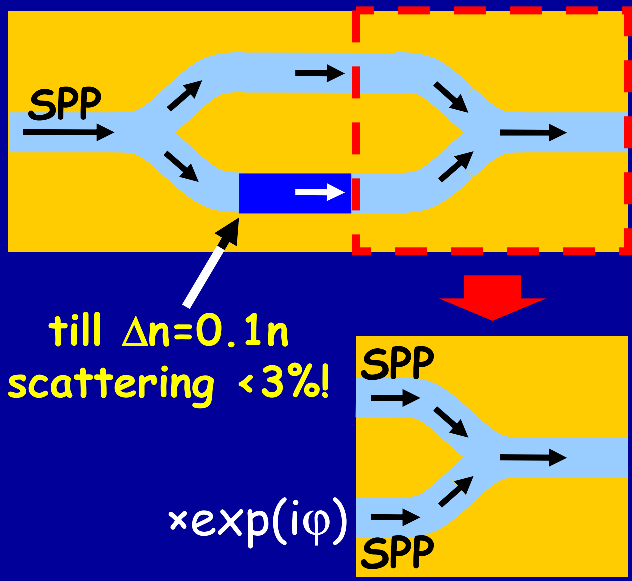
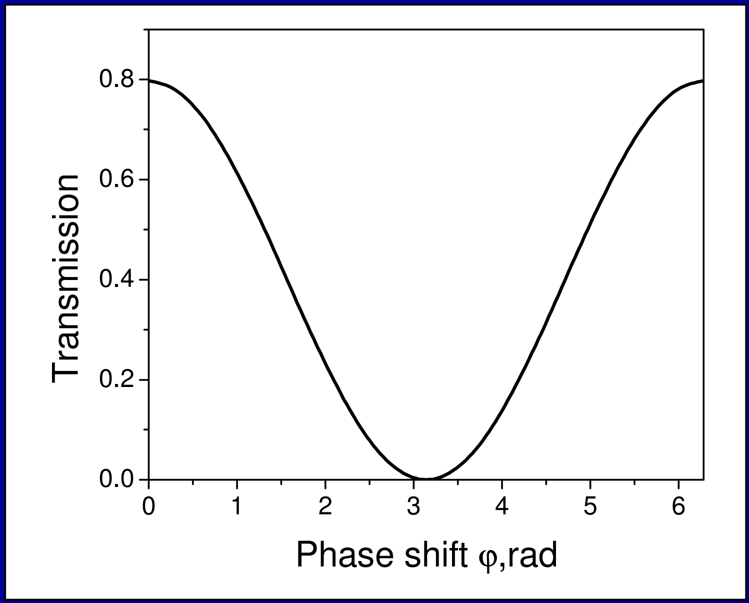
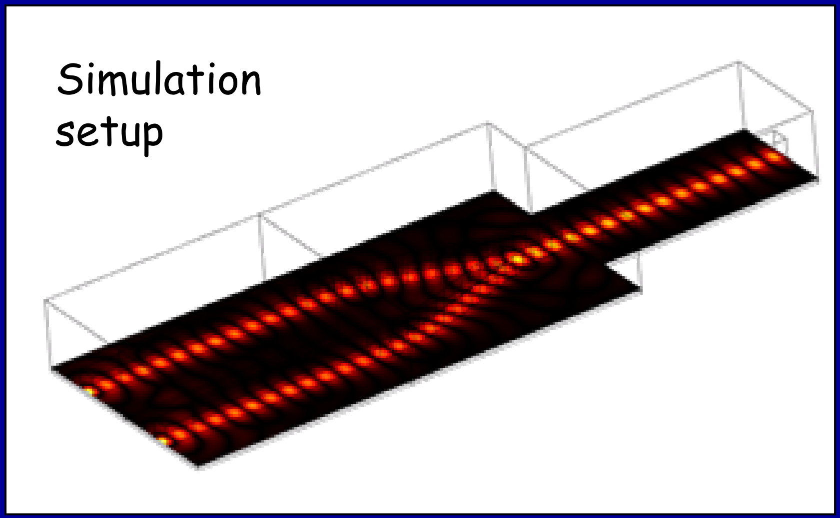
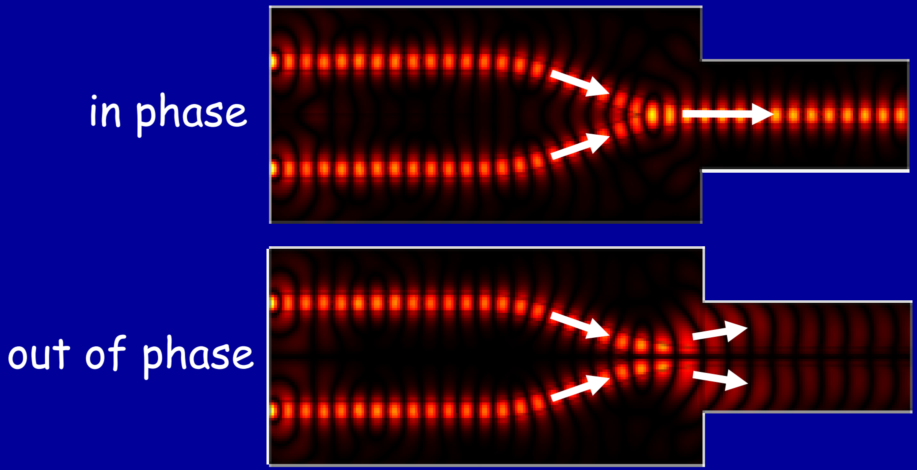
Mach-Zehnder Interferometer









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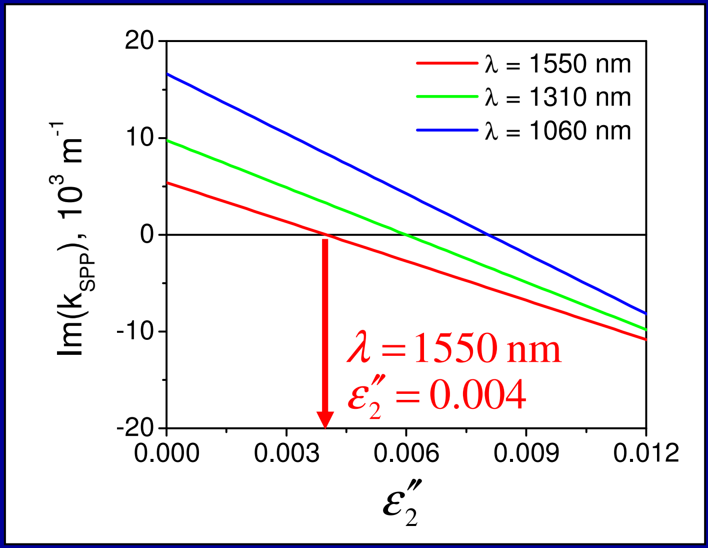
Lossless Propagation of DLSPPWG Mode

Analytical calculation,
plane metal/dielectric (n=1.535) surface case

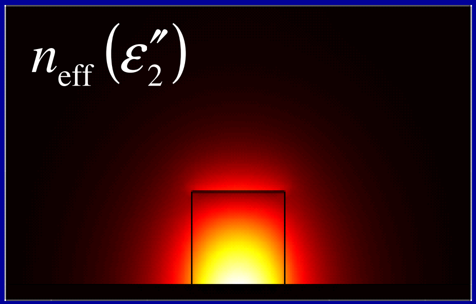
$$k_{SPP} = \frac{\omega}{c}\sqrt{\frac{\varepsilon_1 \varepsilon_2}{\varepsilon_1 + \varepsilon_2}}$$

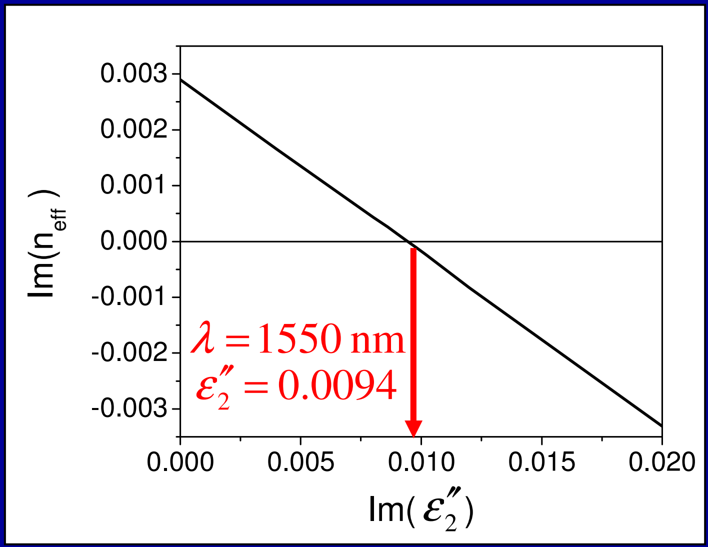
$$\varepsilon_1 = \varepsilon_1' + i\varepsilon_1''$$

ε_2 - real $\xrightarrow{\text{Gain}}$ $\varepsilon_2 = \varepsilon_2' - i\varepsilon_2''$



Numerical simulation,
DLSPPW case





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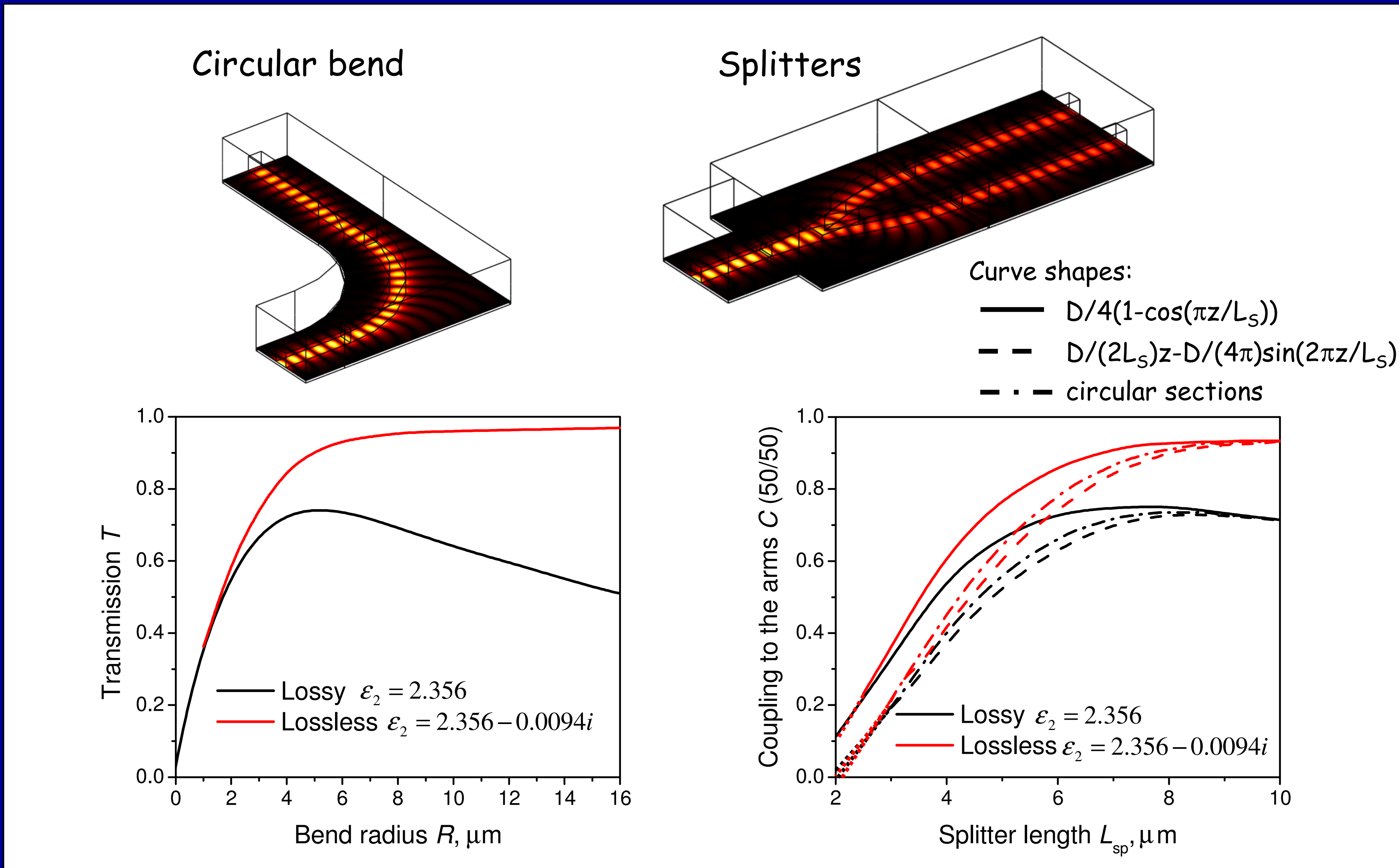
Lossless Bends and Splitters



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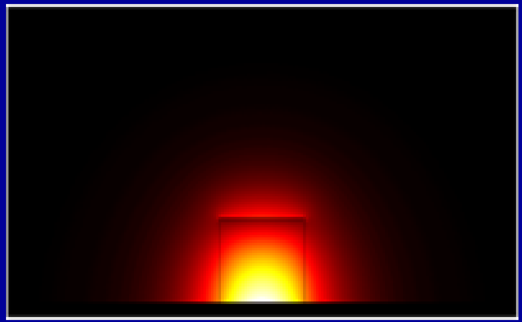
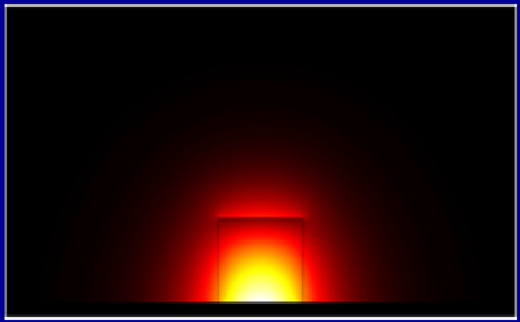
Enhancing (Active) Element

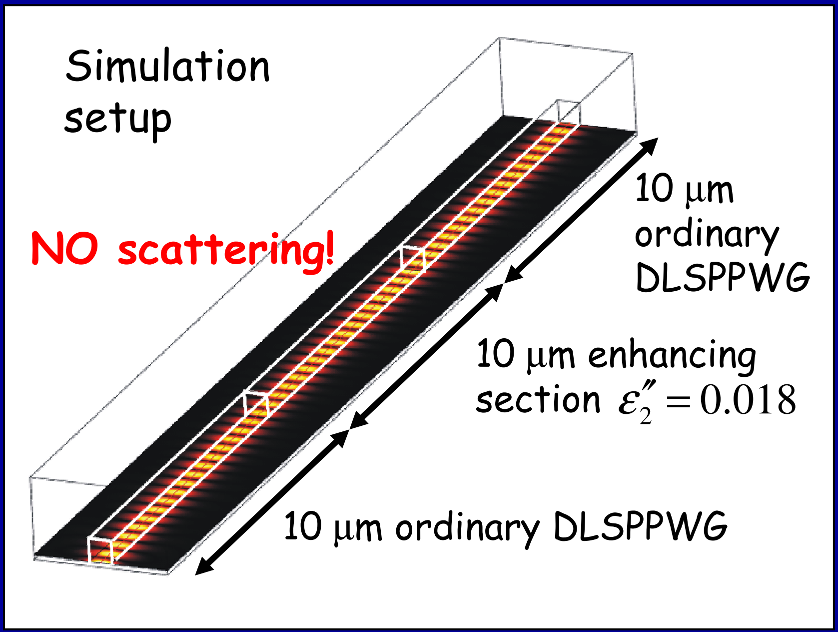
Ordinary DLSPPWG mode

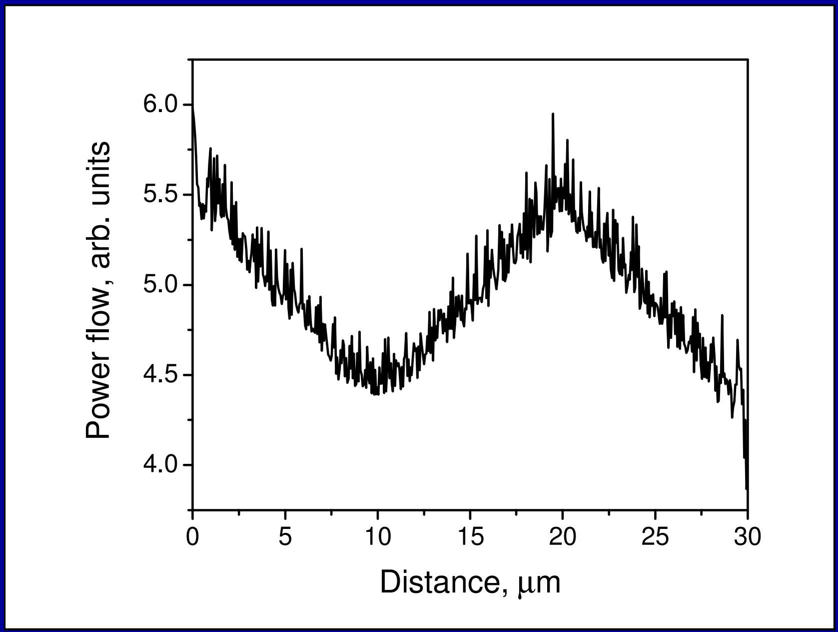


Visually identical

Gain dielectric mode $\varepsilon_2'' = 0.018$







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Conclusions

1. DLSPPW are highly efficient means of localization and guiding of optical mode
2. Found the ultimate level of DLSPPW integration: distance between waveguides can be as small as 2.6 μm
3. Demonstrated highly efficient bending, splitting and reflecting elements on the basis of DLSPPW having just a micrometer size.
4. Experimentally proved guiding properties of main passive DLSPPW elements.
5. Estimated the requirements of lossless propagation of the mode and demonstrated the performance of DLSPPW lossless and active elements.

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