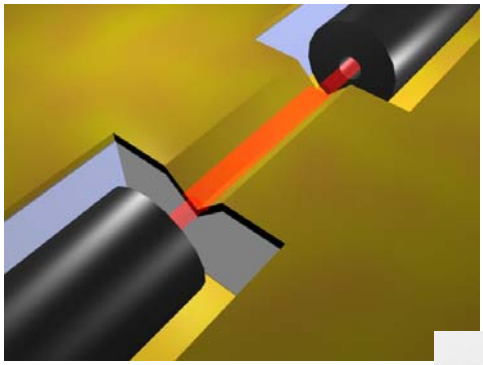
Plasmon confinement in V-groove waveguides fabricated by NanoImprint Lithography



Irene Fernandez-Cuesta, Xavier Borrisé and Francesc Pérez-Murano

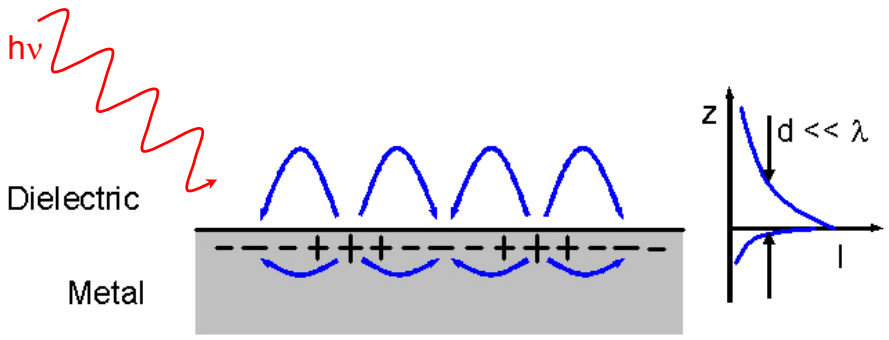
Rasmus Bundgaard Nielsen, Alexandra Boltasseva, and Anders Kristensen

Dominique Heinis and Niek van Hulst

Outlook

- Plasmons: definition, confinement in V-gr., simulations, state of the art
- V-grooves fabrication process: design, description and results
  - Stamp
  - Nanoimprint and post processing
- Optical characterization
  - Far field
  - Near Field
- Conclusions

SURFACE PLASMON POLARITONS - SPPs



•PLASMON (SPP): Quasi-particles resulting from the coupling of **free electrons** in a metal and the **electromagnetic field** of the light.

•SPPs are **evanescent waves**, propagating along the dielectric/metal interface.

Propagation length ~10 - 400 μm (depending on the wavelength of the incident light).

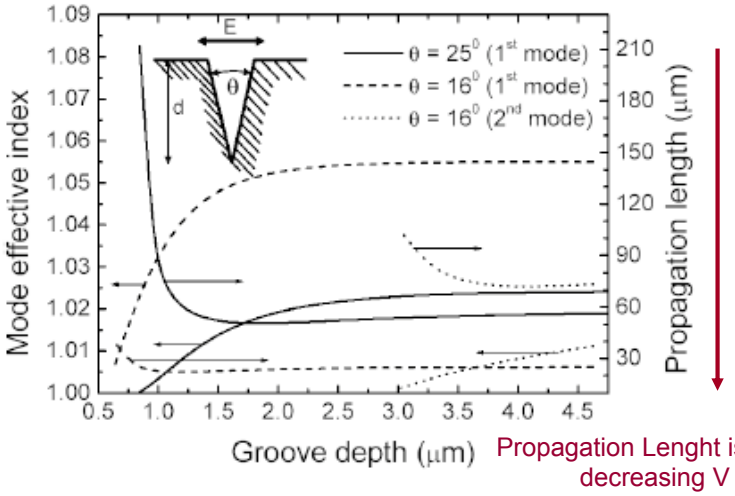
-> Plasmons: suitable for guiding light in sub-λ structures -> nanostructures (waveguides)

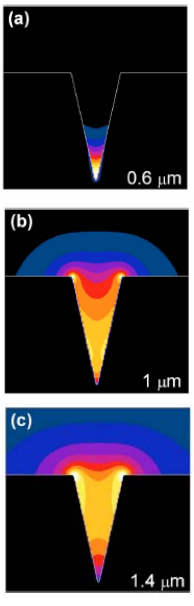
Surface Plasmon Polariton in sub-λ structures:

Channel-Plasmon-Polaritons (CPPs)

V-Groove: SPPs propagating in each side couple at the bottom of the groove.

V-GROOVE





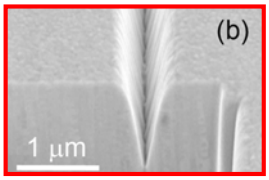
Propagation Lenght is reduced for decreasing V angle

E. Moreno, FJ. Garcia-Vidal, S. G. Rodrigo, L. Martin-Moreno, S. Bozhevolnyi, OPTICS LETTERS, 31, 23, 3447 (2006)

State of the art: First experimental results in v-grooves

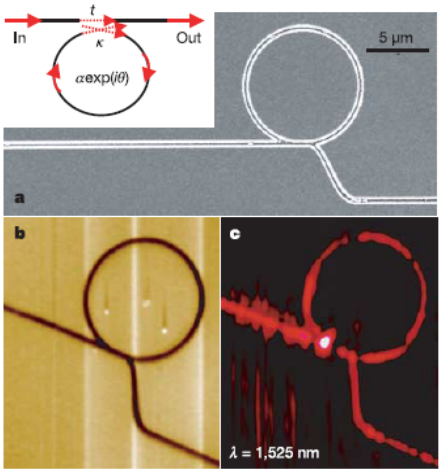
SNOM measurements in v-shape structures

S. I. Bozhevolnyi, V. S. Volkov, E. Devaux, J.Y. Laluet, and T. W. Ebbesen, Nature 440, 508 (2006)

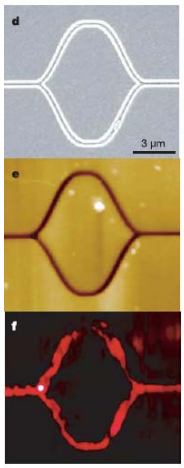


Silver V-Groove made by FIB

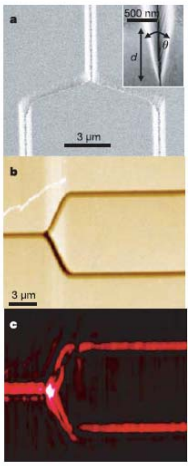
RING RESONATORS



MACH ZENDER INTERFEROMETER

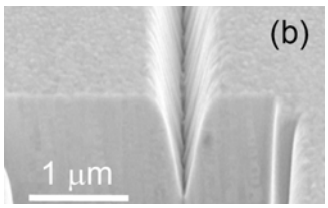


Y-SPLITTER



It is possible to confine and guide light in sub-λ structures

Disadvantage: FIB fabrication is suitable just for demonstrators



Sharp grooves, but it is difficult to control the angle

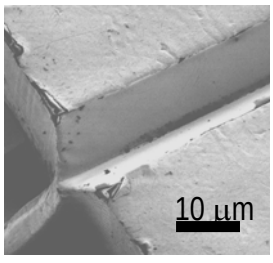
Rough sidewalls

Slow, process in serie

A bigger area has to be milled, for light coupling

Not suitable for fabrication of devices, or ”real” applications

Our proposal: v-grooves fabrication process based in NanoImprint lithography



Fabrication: Nanoimprint + postprocessing

Process in parallel: up to 180 grooves in one single wafer!!

The smoothness is improved

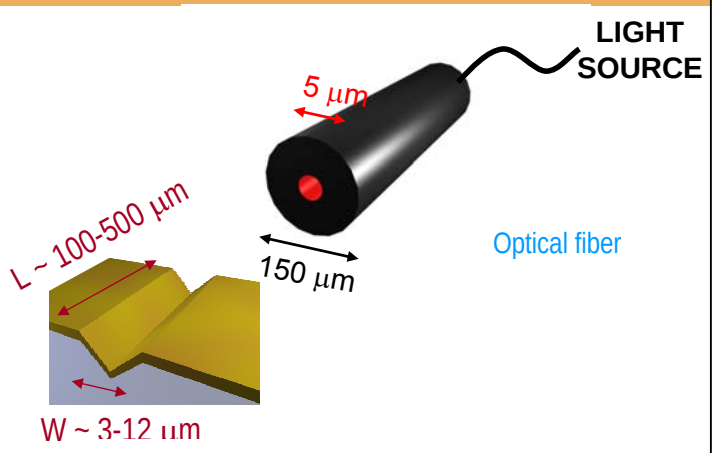
Can be used to fabricate devices

Design and NIL-based fabrication process

V-groove device design

Wafer scale fabrication: different lengths and sizes in the same sample.

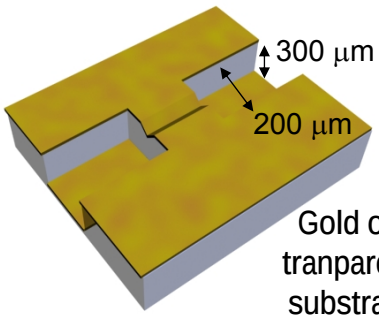
V-Groove: variable length (100-500 μm) and width (3-12 μm), angle = 70º, (fix by the fabrication process)



NIL allows multilevel fabrication in the same step:

Integration of v-groove and deep channels

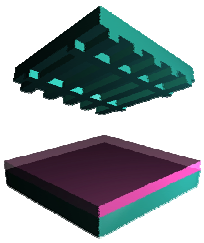
Channels: deep (300 μm) and wide (200 μm), to approach the fibers to the groove



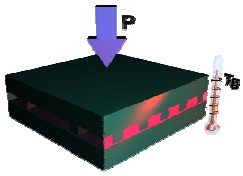
Gold on tranparent substrate

OUTPUT

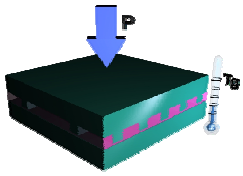
NanoImprinting



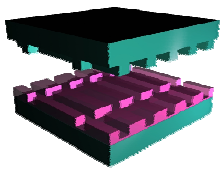
1. Hard stamp
2. Substrate with a polymer layer



3. Heat,
4. Pressure



5. Cool down (with the pressure)



6. Separate

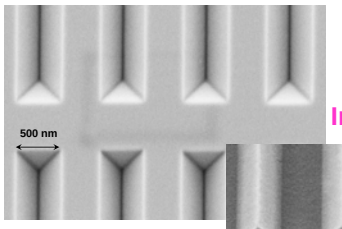
Main advantages:

√ Unlimited resolution (given by the stamp fabrication)

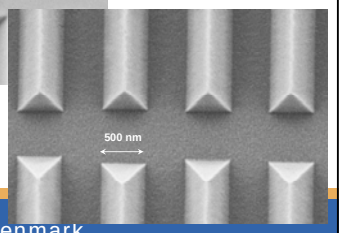
√ **Parallel fabrication** process: 1 sample processing at a time, containing several single chips

√ Simple and cheap process, suitable for large scale fabrication of devices

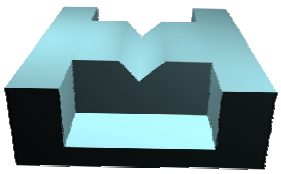
Silicon Stamp



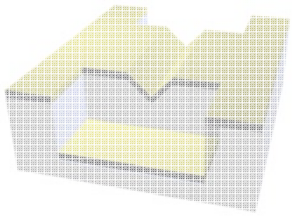
Imprint in PMMA



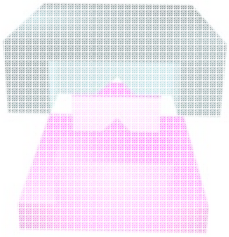
A. Stamp



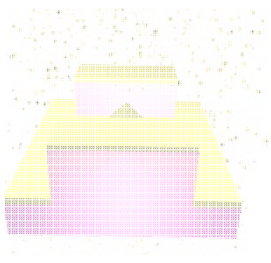
C. Final Structures



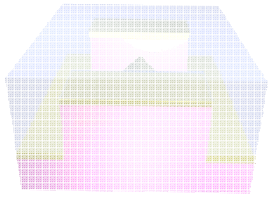
B. Nanoimprint and postprocessing



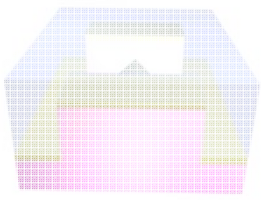
1.Imprint in PMMA



2. Gold deposition

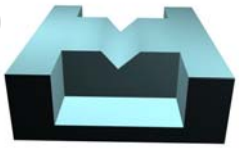


3. Ormcomp deposition (UV curing)

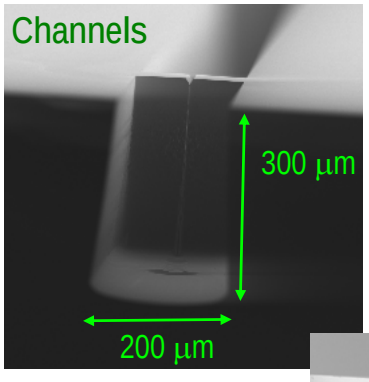


4. Removing PMMA

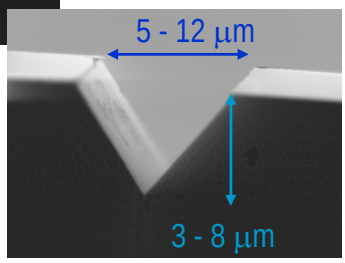
Silicon Stamp



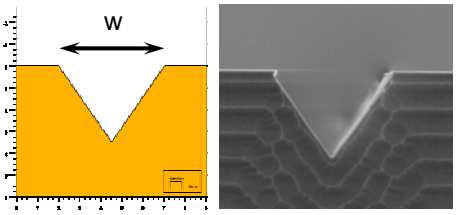
1. RIE



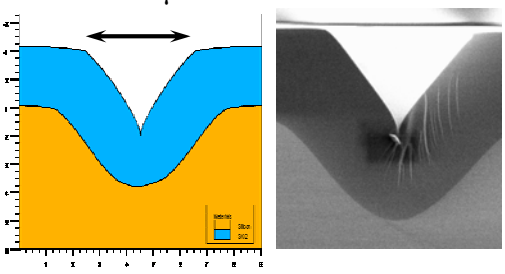
2. KOH V-Grooves



3. Oxidation

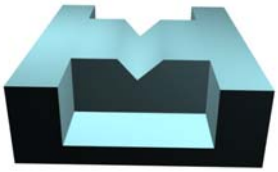


W = 5 μm



6h, 1150ºC

A. Stamp

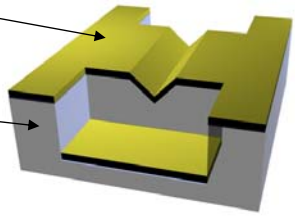


Silicon

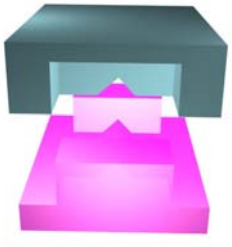
C. Final Structures

Gold (200 nm)

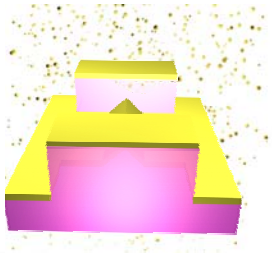
Ormocomp (transparent polymer, from micro resist technology)



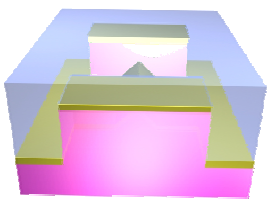
B. Nanoimprint and postprocessing



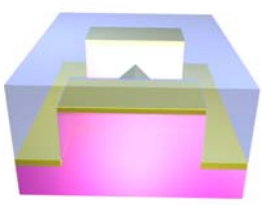
1.Imprint in PMMA



2. Gold deposition

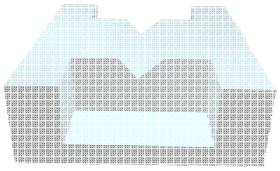


3. Ormcomp deposition (UV curing)

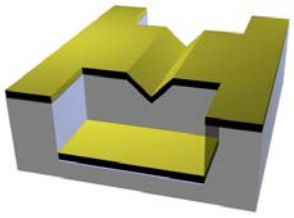


4. Removing PMMA

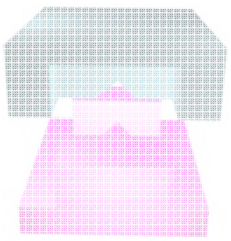
A. Stamp



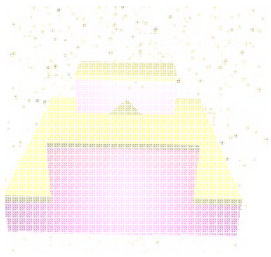
C. Final Structures



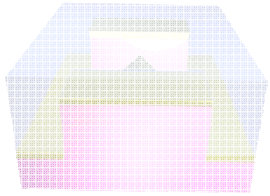
B. Nanoimprint and postprocessing



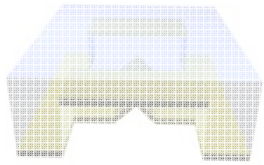
1.Imprint in PMMA



2. Gold deposition

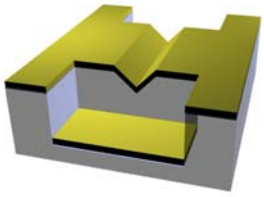


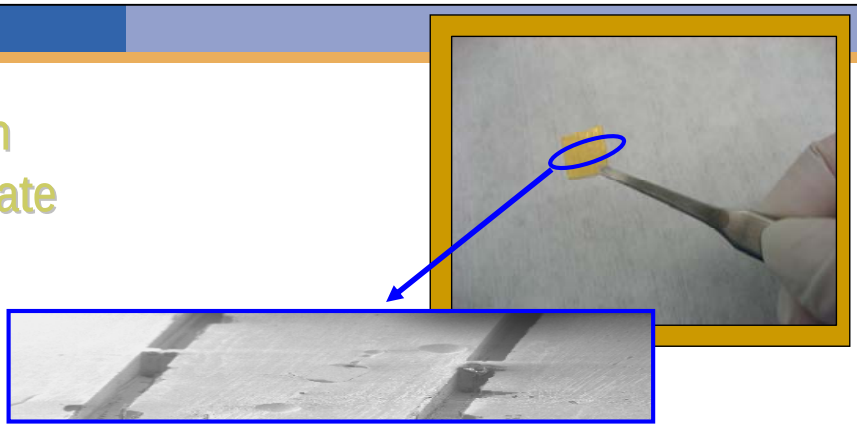
3. Ormcomp deposition (UV curing)

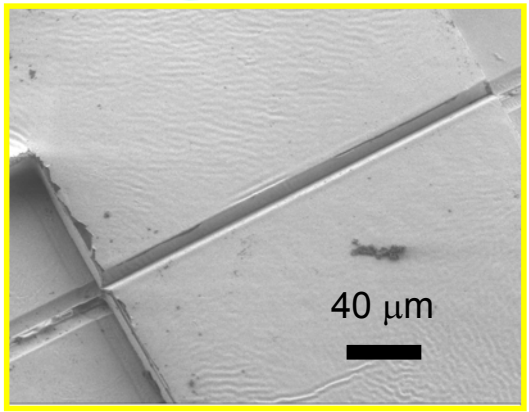


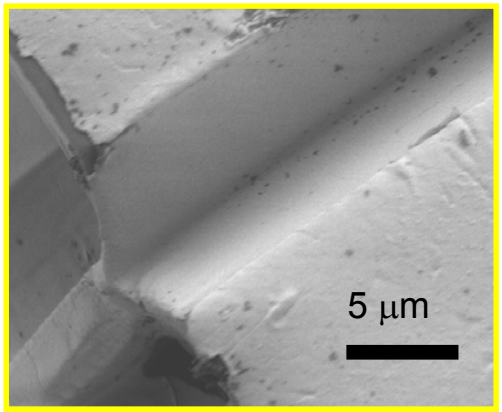
4. Removing PMMA

Gold Grooves on transparent substrate







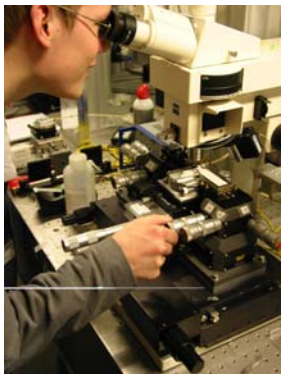


OPTICAL CHARACTERIZATIONS

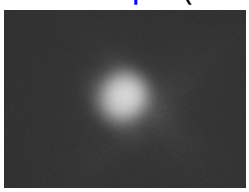
I. Far field images

II. Near field: SNOM characterization

Far field characterization

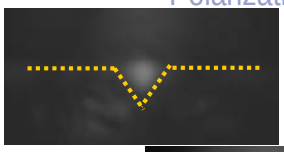


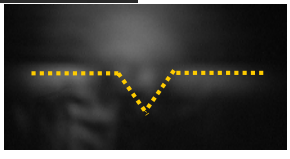
1.Fiber Output (blank)



3. Output of the groove (V)

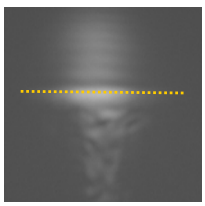
Polarization TM

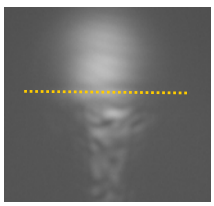




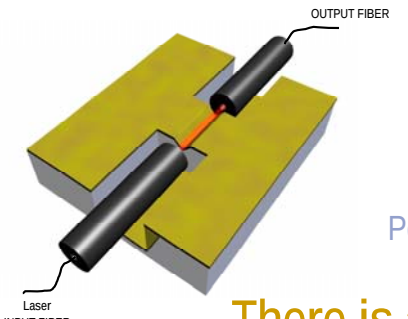
Polarization TE

2. Sample surface



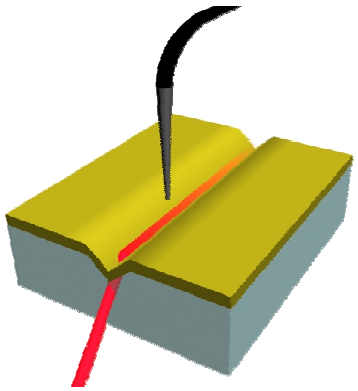


Polarization TM Polarization TE



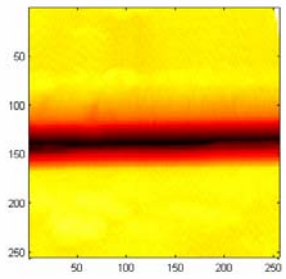
There is a clear output mode for TM polarization

Optical Near Field characterization (SNOM)

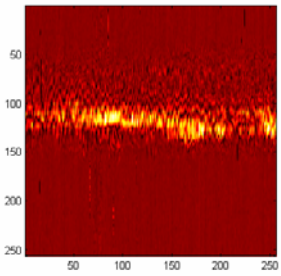


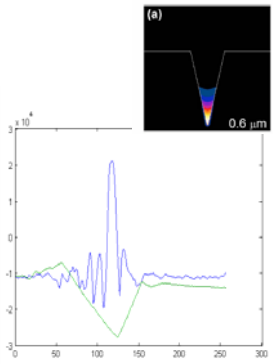
RED LIGTH

Topography

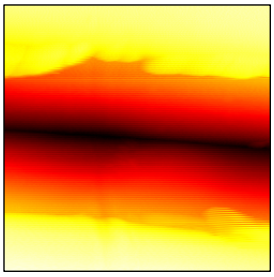


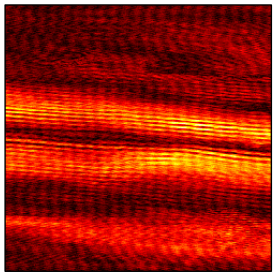
Intensity

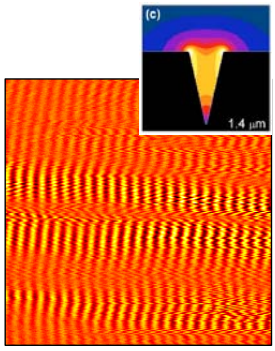




IR LIGTH



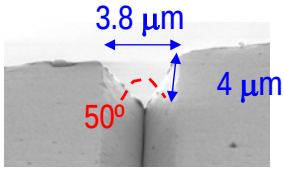




Topography Intensity Phase

Light couples and propagates inside the grooves

Evaluation of the performance for light guidding



V-groove geometry:

- width = 3.8 μm
- depth = 4 μm
- apex angle = 50°

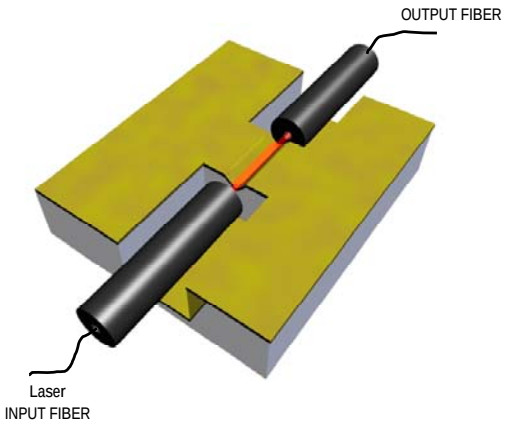
SNOM measurements (at $\lambda \cong 1525$ nm):

- Propagation length = 120µm
- Confinement: FWHM =1.33 μm

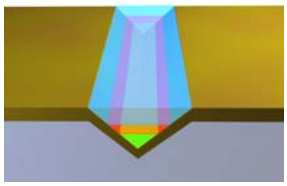
- CPPs are **less confined** than in previous works (FIB), due to the large apex angle.
- This results in **larger propagation lengths** -> good compromise between confinement and losses.

Use for (bio)sensing: Fiber-to-fiber measurements

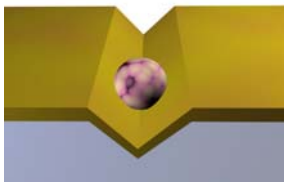
Change in the output signal as a function of the media inside the V-waveguide.



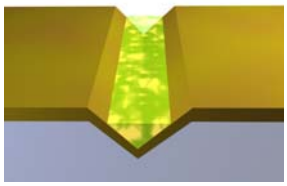
Different Layers



Cells/Nanoparticles



Micro Fluidic Channels?



Conclusions

- Plasmon confinement in v-grooves has been demonstrated recently.
- A method for parallel fabrication of v-grooves integrated with deep channels, in wafer scale, has been presented.
- Optical characterization in far field show an output mode for TM polarization
- SNOM measurements show plasmon confinement and light guiding in the waveguides.