Control of surface plasmon polaritons for optoelectronic applications

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Abstract

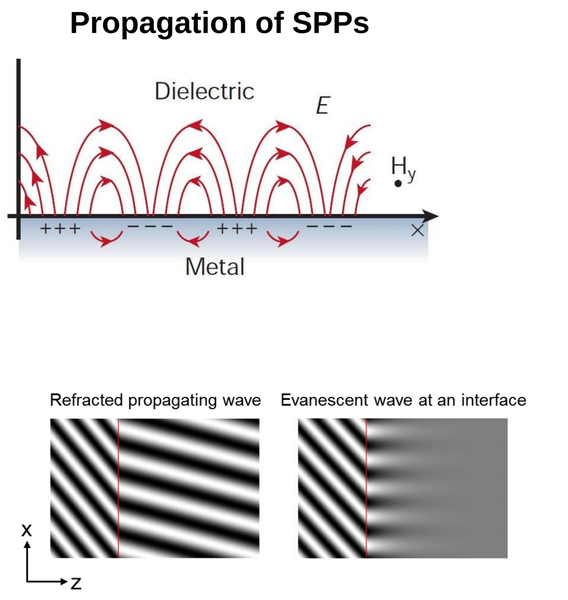
The control of surface plasmon polaritons (SPPs) has been an important subject in developing optoelectronic devices in nanophotonics.

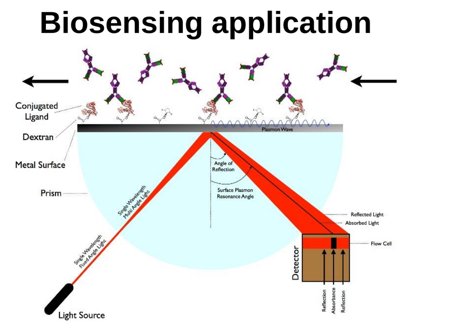
In most of the previous studies, control has been performed through the manipulation of the incident angle of the light, its polarization state, and the surface structures patterned on the metal surface.

In this study, we demonstrated the generation and control of SPPs by using a transfer matrix measurement and wavefront shaping, and proved that the SPPs can be controlled by higher degrees of freedom than conventional research.

Introduction

What is the Surface Plasmon Polaritons (SPPs)





SPPs are propagating waves along a metal-dielectric interface.

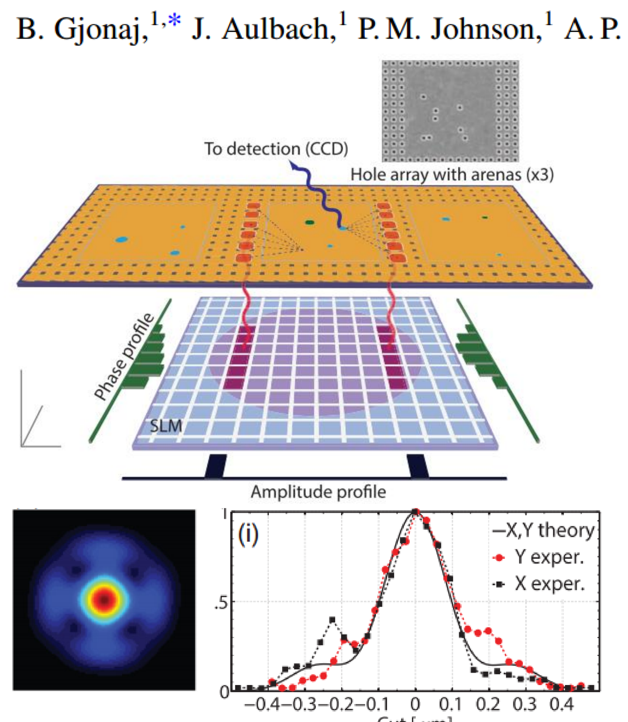
Because of high field enhancement, SPPs are used on biosensing application.

Surface plasmonic wave contains high frequency information, but strongly confined on the surface. To detect the SPPs, we need near-field detection system.

Motivation

Focusing and Scanning Microscopy with Propagating Surface Plasmons [1]

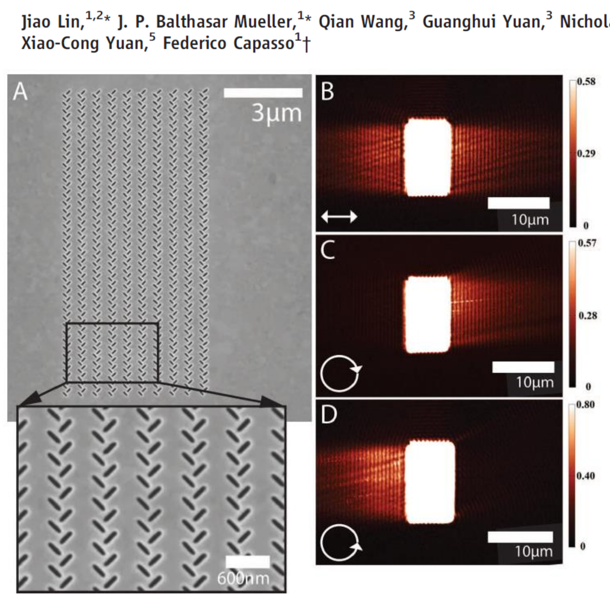
B. Gjonaj, J. Aulbach, P. M. Johnson, A. P. Mosk, L. Kuipers, and A. Lagendijk



- SPPs focusing by wavefront shaping
- Use only single line as source of SPPs

Polarization-Controlled Tunable Directional Coupling of Surface Plasmon Polaritons [2]

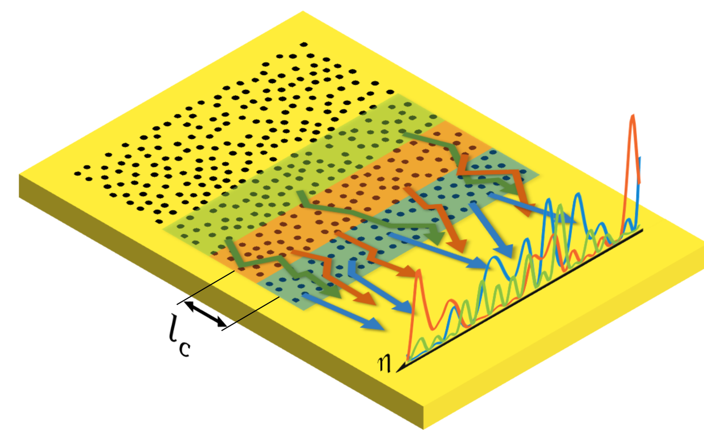
Jiao Lin, J. P. Balthasar Mueller, Qian Wang, Guanghui Yuan, Nicholas Antoniou, Xiao-Cong Yuan, Federico Capasso



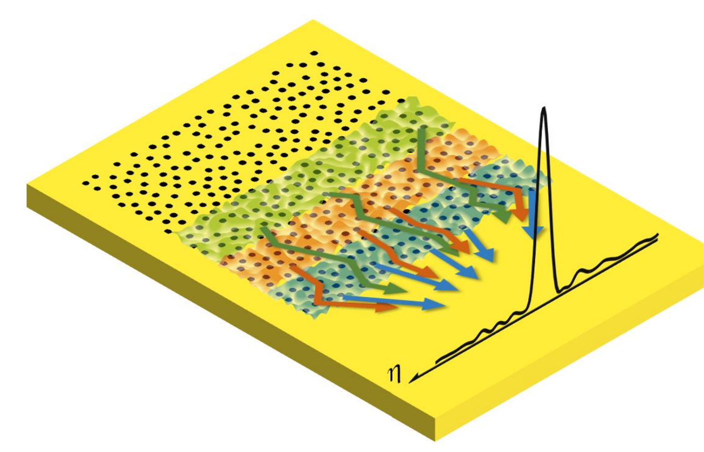
- Periodic patterns on gold film
- Control the propagation direction of SPPs by changing polarizaion
- There are only two output channels

Concept

Using 2D array of disordered nanoholes



- The blue, red and green curves at the sampling line are the SPP fields originating from the representative far-field illumination of the blue, red and green rectangular areas, respectively.
- The SPPs generated at each illumination become uncorrelated on their way to the sampling line due to their random multiple scattering. Therefore, the output channel number will be increased.



- By wavefront shaping, we can focus SPPs where we want.

Numerical and theoretical analysis

- The scattering occurs in two different pathways.

1. In-plane scattering which alters the propagation direction of the SPPs
   - It gives rise to the decorrelation of SPPs.
   - It plays an important role in increasing the number of effective transmission channels.
   - If there are $m = [L/l_c]$ slabs, effective number of antennas for the entire pattern is given by $m \times N^{1D}$. (l_c : characteristic length, $N^{1D} = 2L/\lambda_{SPP}$)
2. Out-of-plane scattering to the far-field waves.
   - It works the same way as absorption loss, thereby attenuating the intensity of the SPPs.
   - The decay of intensity takes the form

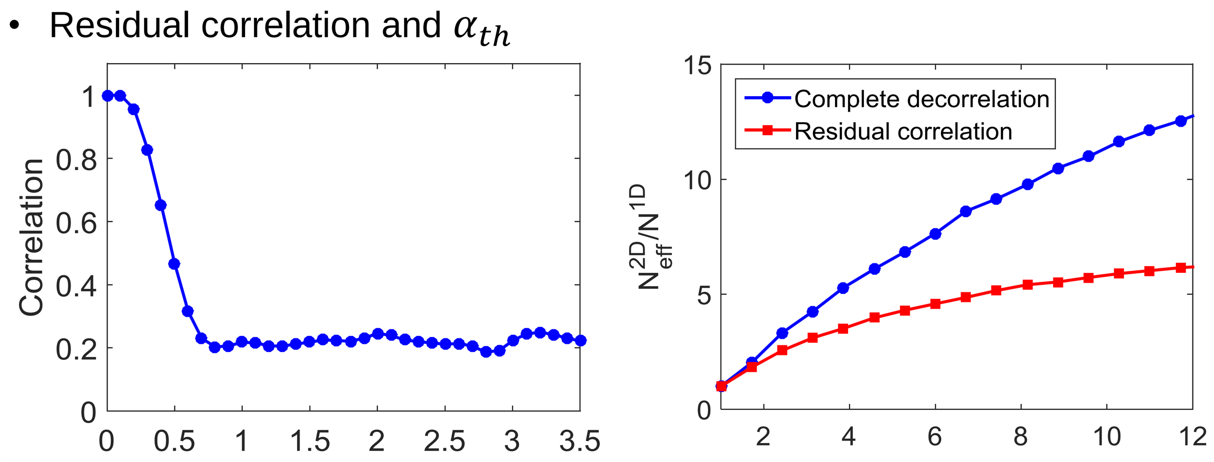
$$T(y) = \frac{l_t}{y+c} exp(-y/l_a)$$

(l_a : absorption length, l_t : transport mean free path, c : extrapolation length)

- We defined the effective channel number N_{eff}^{2D} by the ratio of signal intensity at the target point to the average intensity in the background (SNR) for SPP focusing.

$$N_{eff}^{2D} = \frac{\left|\sum_{j=0}^{m-1} \sqrt{T(jl_c)}\right|^2}{\sum_{j=0}^{m-1} T(jl_c)} N^{1D} \equiv \alpha N^{1D}$$

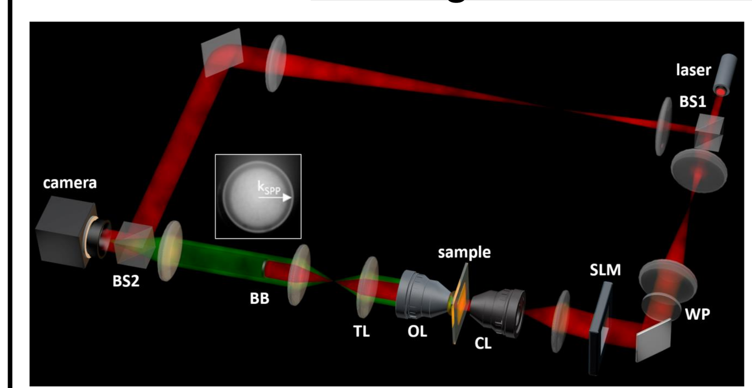
- Residual correlation and α_{th}

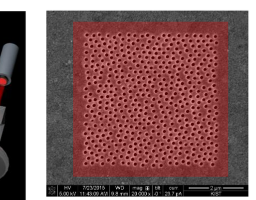


- When $m = [L/l_c] = 10$, $\alpha_{th} \approx 11$ (complete decorrelation)
  $\alpha_{th} \approx 6$ (residual correlation)

Experimental Setup

Leakage Radiation Microscope





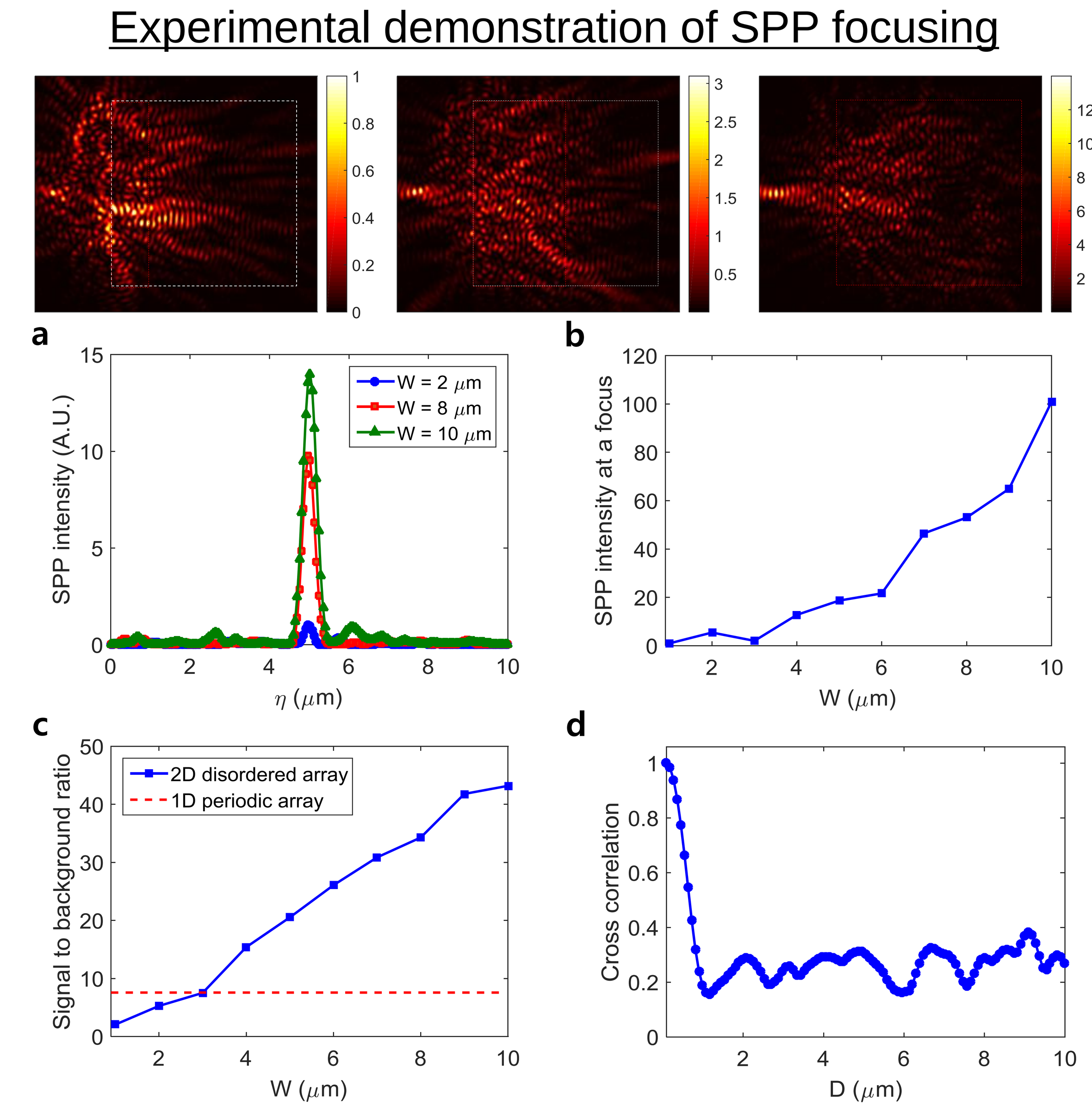
Sample

- Gold coating on glass substrate
- Thickness of the gold film : 100 nm
- Each hole diameter : 100 nm

- We controlled the phase using SLM.
- Since the metal is thin enough, the SPPs generated between the air and the gold film come out leak to the opposite side. So, SPPs can be detected by objective lens.

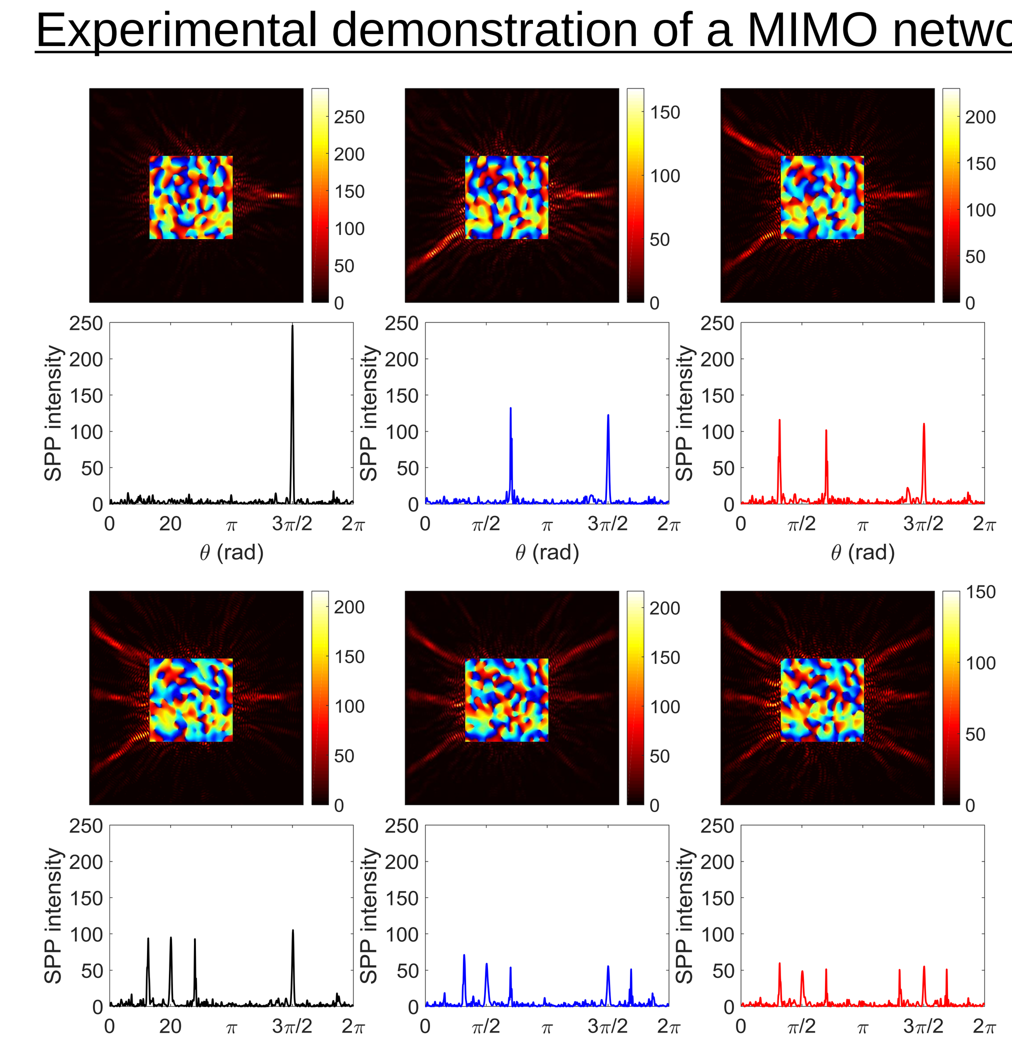
Experimental result

Experimental demonstration of SPP focusing

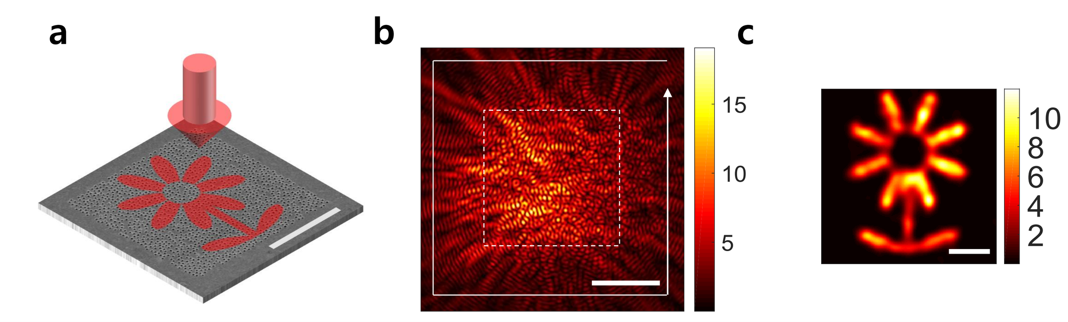


- Experimentally observed enhancement factor is $\alpha_{exp} \approx 6$.

Experimental demonstration of a MIMO network



Experimental demonstration of image delivery



Reference

[1] B. Gjonaj, J. Aulbach, P. M. Johnson, A. P. Mosk, L. Kuipers, and A. Lagendijk, "Focusing and Scanning Microscopy with Propagating Surface Plasmons", Phys. Rev. Lett. 110, 266804 (2013)

[2] Jiao Lin, J. P. Balthasar Mueller, Qian Wang, Guanghui Yuan, Nicholas Antoniou, Xiao-Cong Yuan, Federico Capasso, "Polarization-Controlled Tunable Directional Coupling of Surface Plasmon Polaritons", SCIENCE, 340, 6130, 331-334 (2013)