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A Bright Puzzle and its Dark Solution: Hyperspectral Imaging of Plasmonic Nanostructure Arrays

Ya'akov Mandelbaum*[,1,2,3], Abhijit Sanjeev[1], Eugene Brozgol[1], Avi Karsenty[1,2,3], Zeev Zalevsky[1], David Zitoun[1]

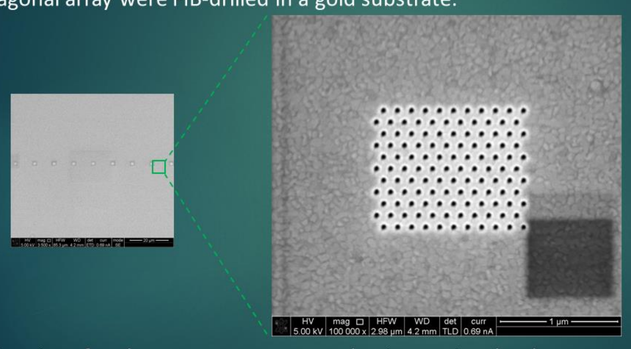
* yaaqovm@gmail.com 1 **BINA** 2 ALEO 3 Lev Academic Center-Jerusalem Center of Technology (JCT)

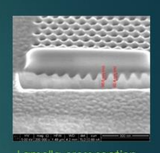
Abstract: Nanostructure arrays were designed for optimal performance as pixels in an advanced imaging device. The 'pixels' were fabricated by Focused Ion Beam (FIB), and their plasmonic behavior was investigated optically.

Holey Tablets – Nano-hole Arrays

1

Rectangular patterns, 1-2µm on a side, containing 121 nanoscale cavities arranged in a hexagonal array were FIB-drilled in a gold substrate.





Lamella cross-section displaying cavity depths.

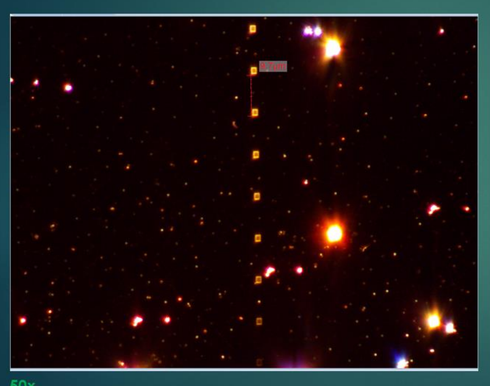
DT [us]	Depth [nm]
0.25	26
0.5	50
1.0	70
1.5	90
2.0	108

A series of such patterns were created at increasing depths, parameterized by the ion-beam dwell-time. Using SEM imaging, depths were determined to span the range 25-110nm.

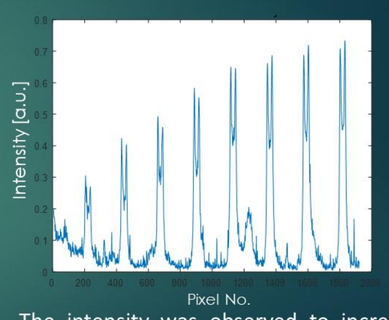
Lights in the Dark

2

To gauge plasmonic enhancement, optical scattering was measured using **dark field** microscopy.



50x

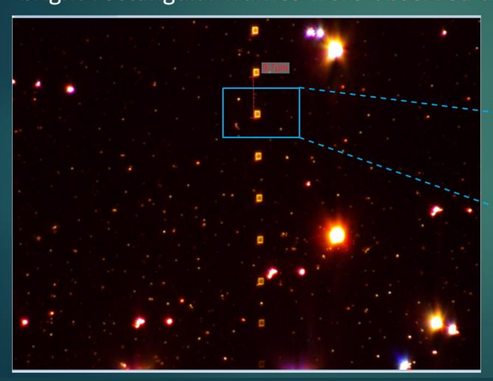


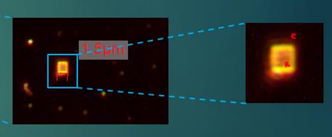
The intensity was observed to increase linearly with the depth.

The Puzzle of the Empty Frames

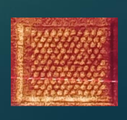
3

The **morphology** however was surprising - rather than solid rectangles, bright rectangular frames were observed around a dark interior.





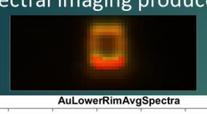
Yet **Kelvin Probe** measurements clearly display the field in the interior.

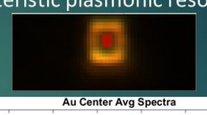


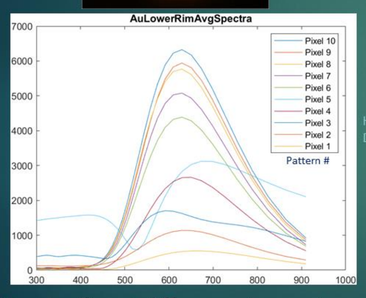
Over the Rainbow – Hyperspectral Imaging

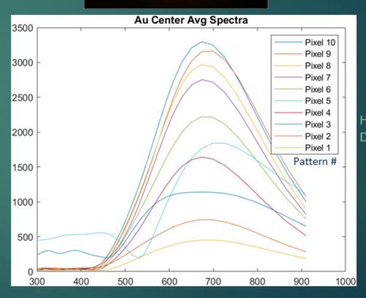
4

Hyperspectral imaging produced spectra with characteristic plasmonic resonant curves.







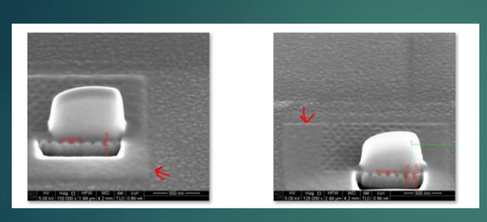


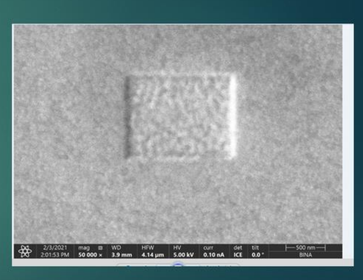
No significant difference in spectra was observed between the bright perimeter and the dark interior ⟹ the frames are not due to an excitation localized on the perimeter.

Taking Control

5

In parallel a difference in **surface texture** between the pixels and the surrounding bulk was noted, suggesting **annealing** due to the ion-beam.



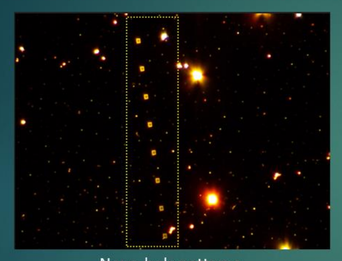


'Control patterns' were fabricated to test this – **empty rectangles** exposed uniformly to a low-dose ion-beam.

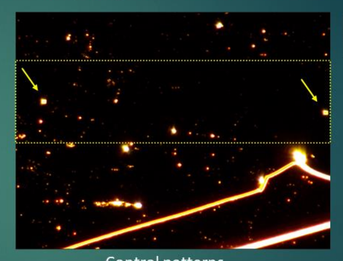
(Losing) Control

6

The control patterns were found to be significantly brighter than the nanohole arrays.



Nano-hole patterns



Control patterns

Magnification	X100
Exposure Time	267 ms

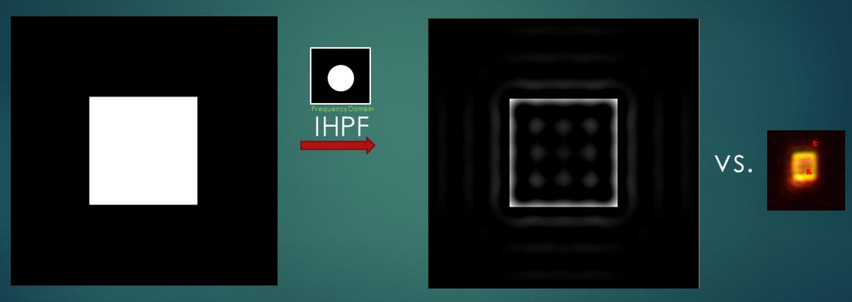
- Control Patterns are **Brighter!**

Evidently the hole depth is not the only factor which affects scattering intensity; other factors, in particular surface quality, can have a stronger effect.

Filling in the Picture A Dark Solution to the Puzzle

7

The physics of dark-field mode is the key: Fourier optics shows that dark-field collection acts as a hi-pass filter. Coherent illumination is assumed.



A simple computation using an Ideal Hi-Pass Filter (IHPF) reproduced the essential characteristics of the measured images.

➢ The illumination is evidently coherent on the scale of the object.

Conclusions

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1. **Scattering intensity** increases with cavity **depth** and **surface quality** – and with ion beam **exposure time** in general.
2. A **dark interior** of nanostructure-pattern scattering images is **inherent to dark-field** mode.
3. Coherence length of the incandescent illumination is ≳ 1-2µm.

Directions for Further Investigation:

- Hi-contrast polarization microscopy will be used to obtain a solid image of the patterns .
- Adding blurring due to (finite-aperture) diffraction to the simulation - ie. an ILPF - should improve correspondence to measurement.