Design, Simulation and Fabrication of Plasmonic Pyramid Substrates for Cell Transfection

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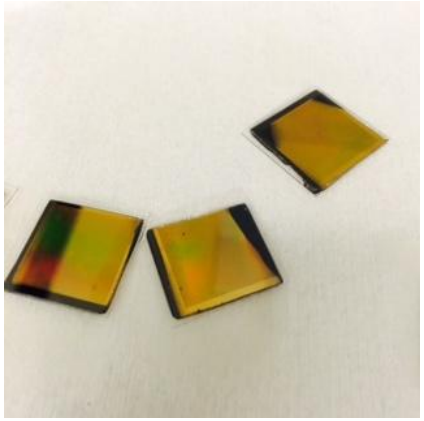
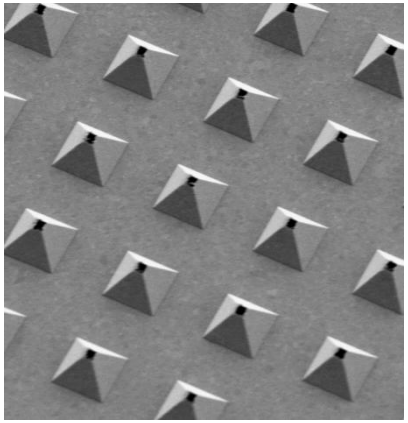
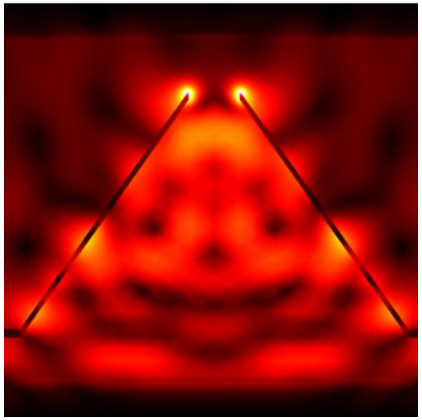
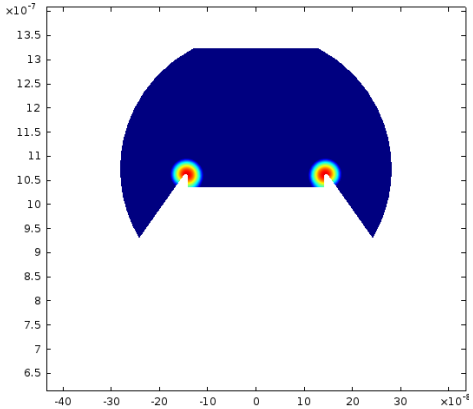
[4]Massachusetts Institute of Technology (United States)
[5]École Polytechnique de Montréal

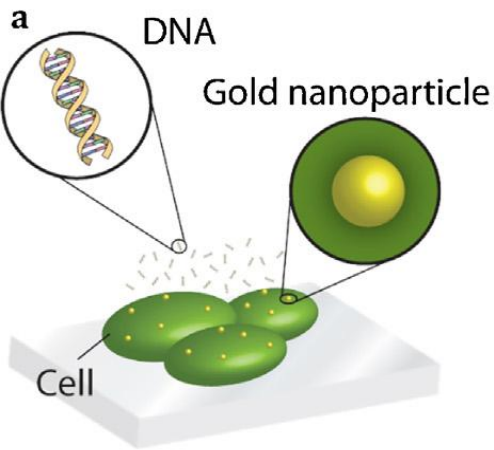






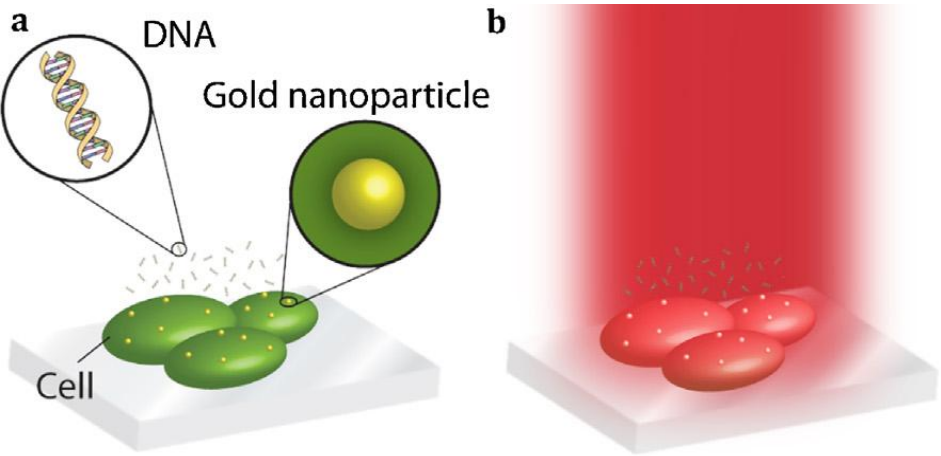


Nanoparticles attach to the cell membrane



Plasmonics for pulsed-laser cell surgery: Fundamentals and applications *E. Boulais et al. Journal of Photochemisty and Photobiology C: Photochemistry Reviews 2013*

Irradiating AuNPs near cells creates pores



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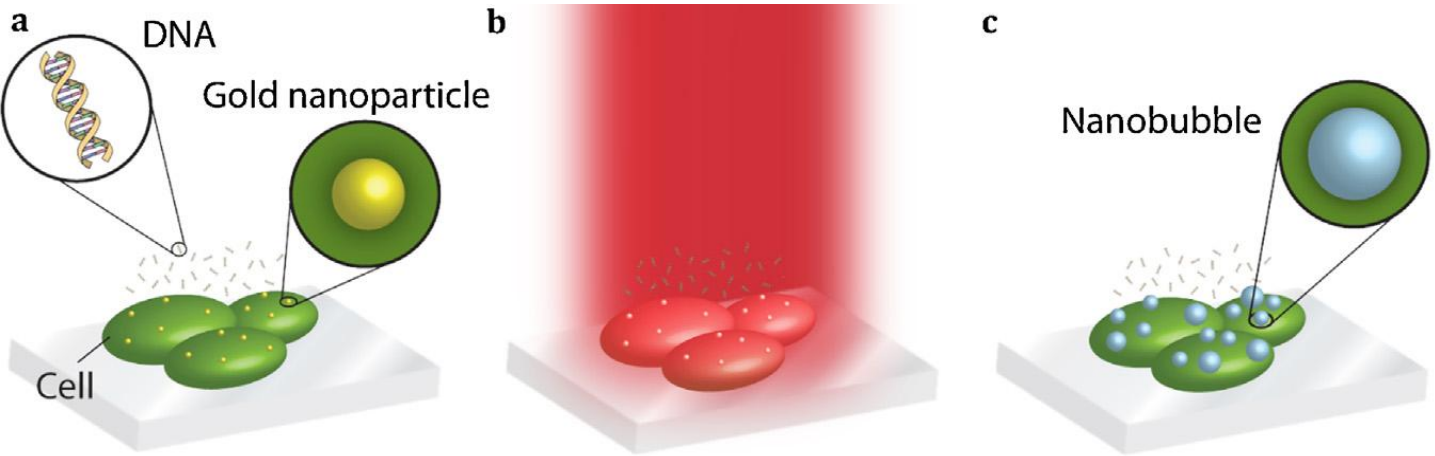

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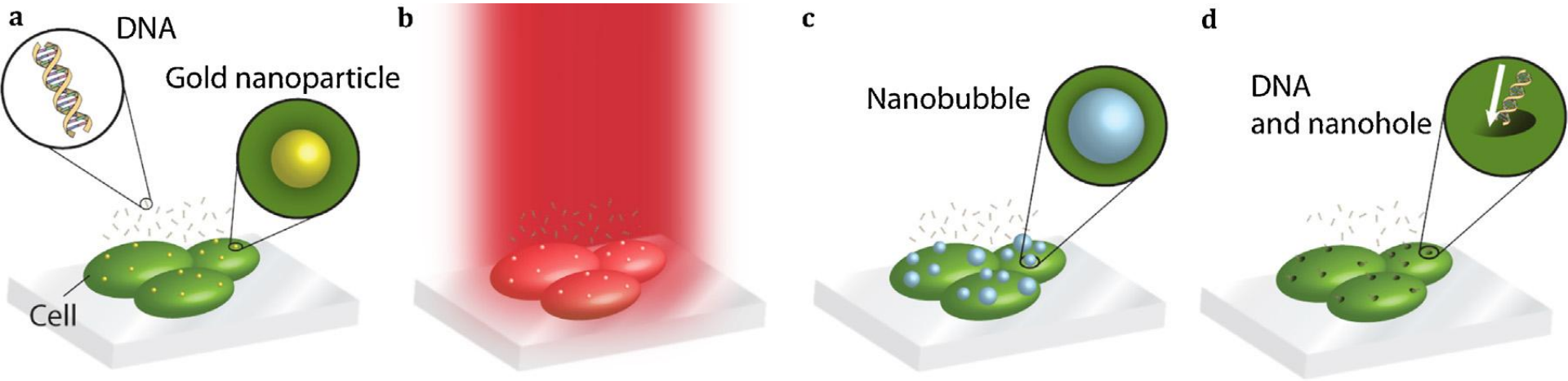
External molecules can enter the cell



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External molecules can enter the cell

Goal: Plasmonic effect that creates pores without particle residue

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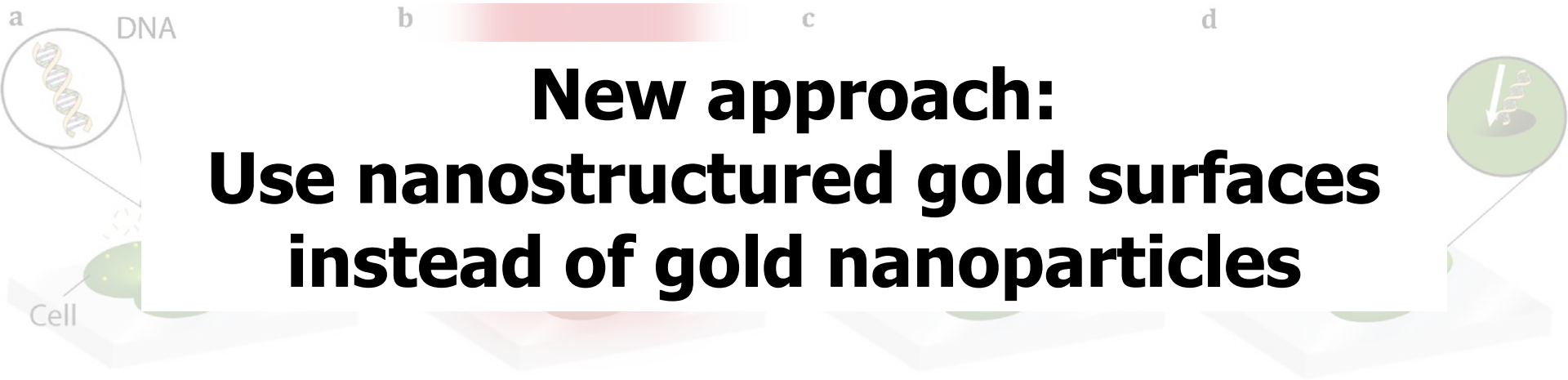
External molecules can enter the cell



New approach:
Use nanostructured gold surfaces instead of gold nanoparticles

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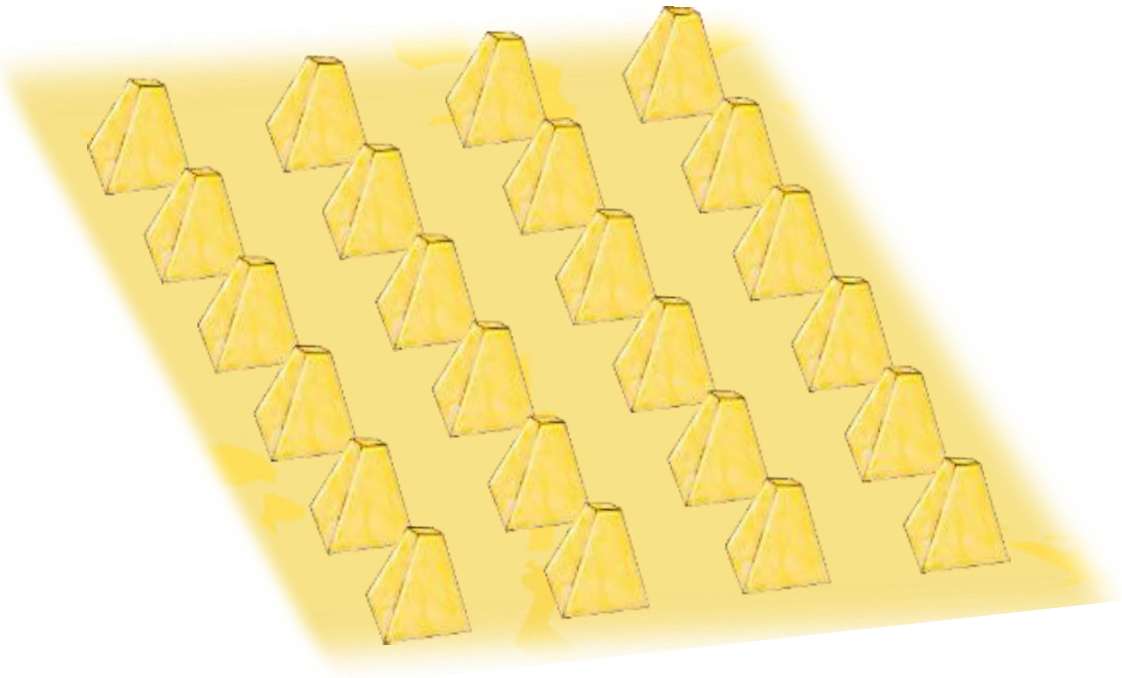
Design aspects

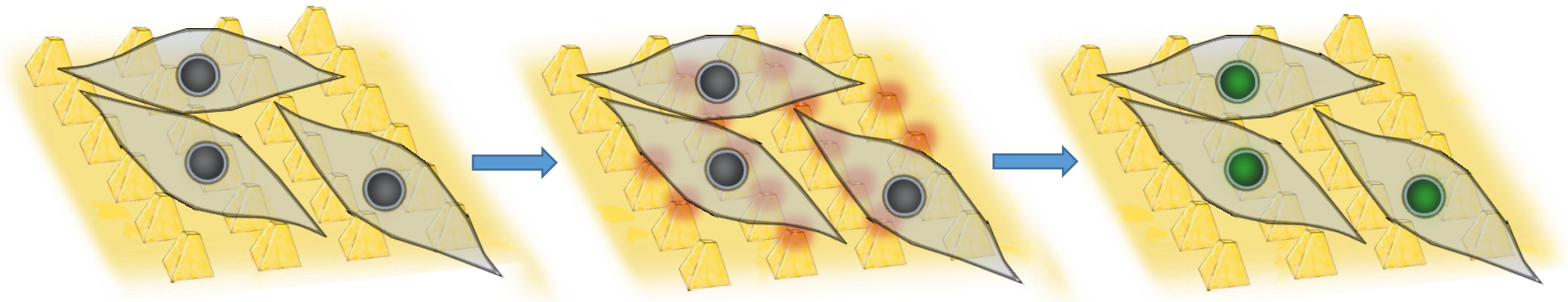
1. Easy to Fabricate/Large-Scale-Fabrication
2. Adjustable
3. Strong Plasmonic Effect for Efficient and Localized Poration
4. Robust/Stable

Proposed structure

Gold Pyramids with Nano-Apertures



Experimental procedure



Cells growing on the Plasmonic Substrate

fs-laser irradiation

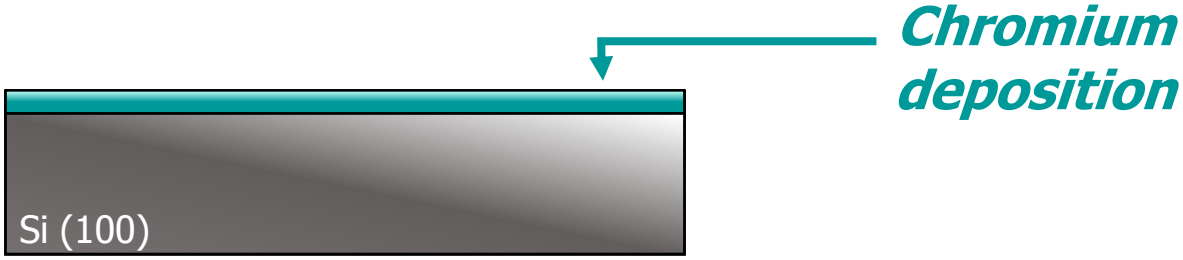
Gene Expression

Outline

Fabrication

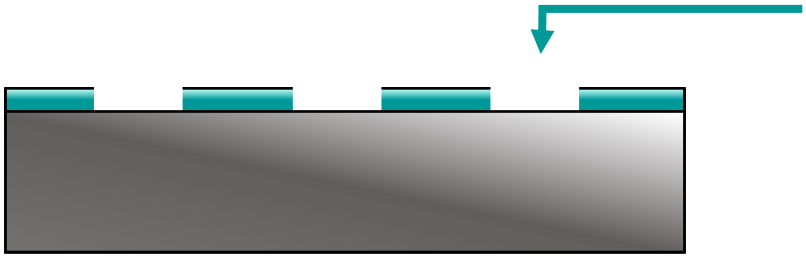
Simulation and Characterization

Fabrication



Fabrication

E-Beam Lithography
or
Photolithography



Negative squares
of Cr thin films

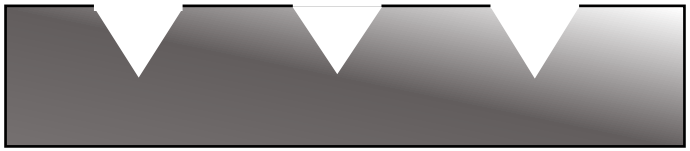
Fabrication

KOH Anisotropic etching

Inverted pyramids

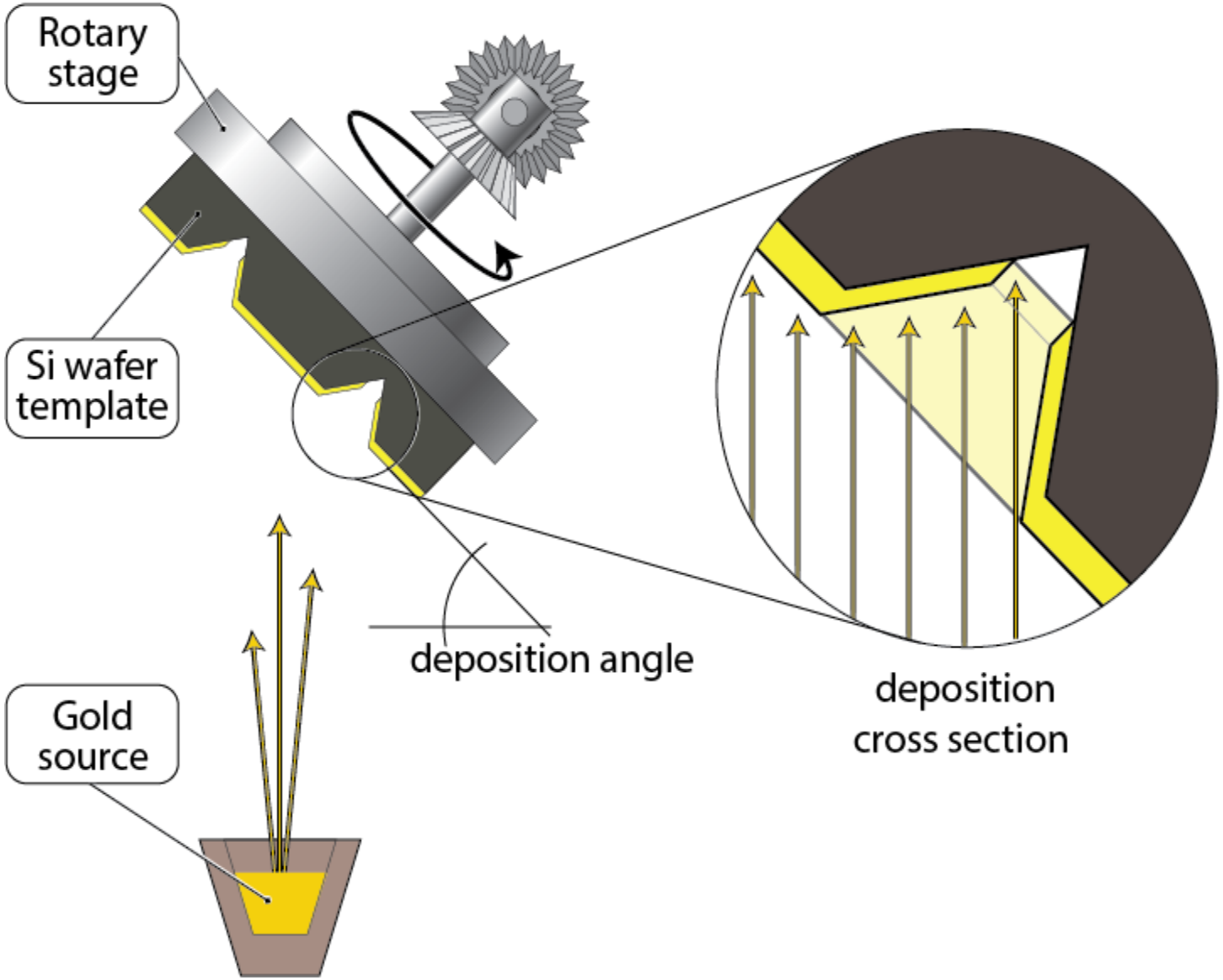
Fabrication

Chromium etch

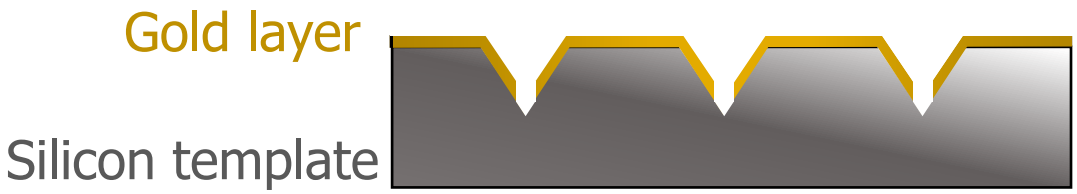


Template

Fabrication

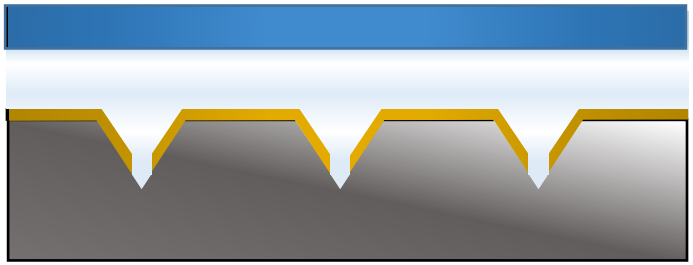


Fabrication



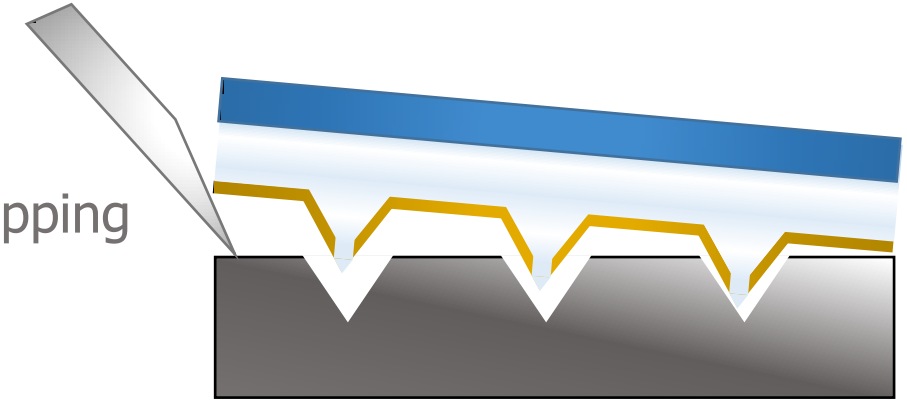
Fabrication

Glass coverslip
UV-cured glue



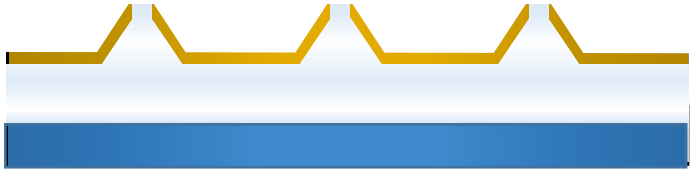
Fabrication

Template-stripping

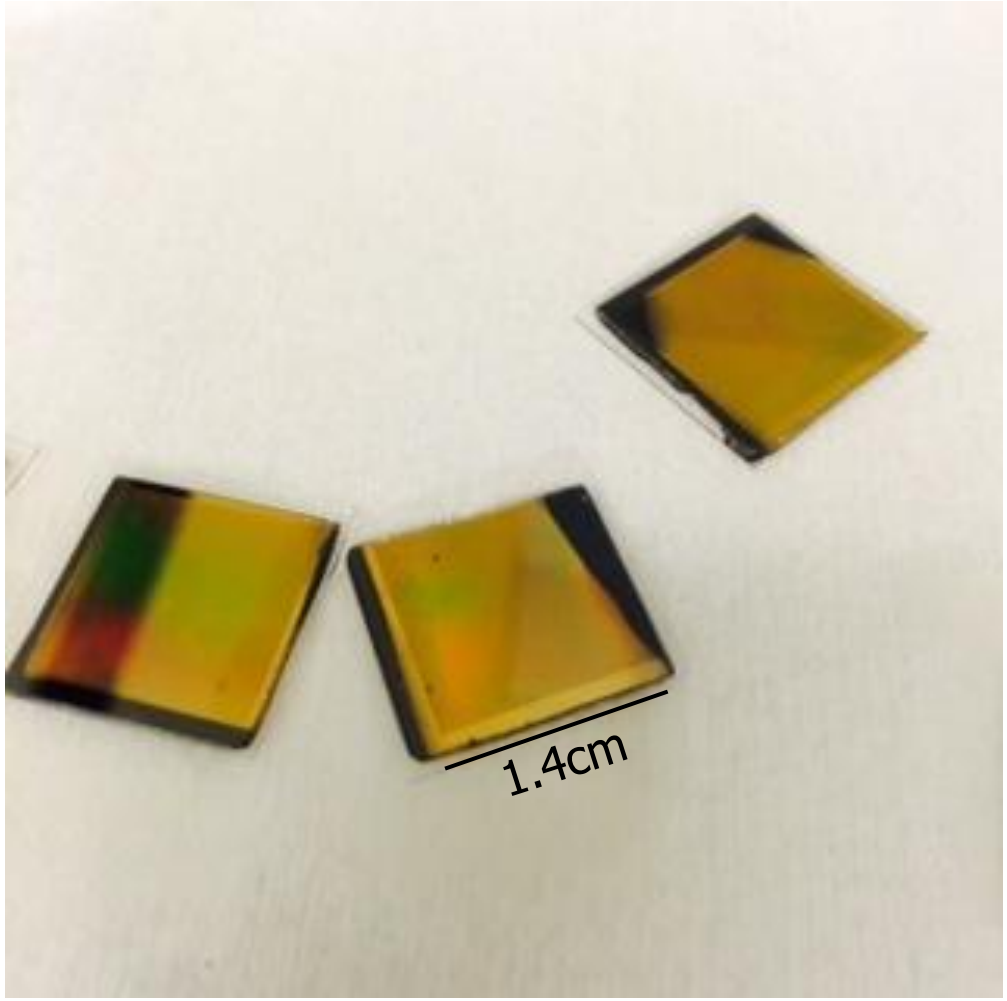


Fabrication

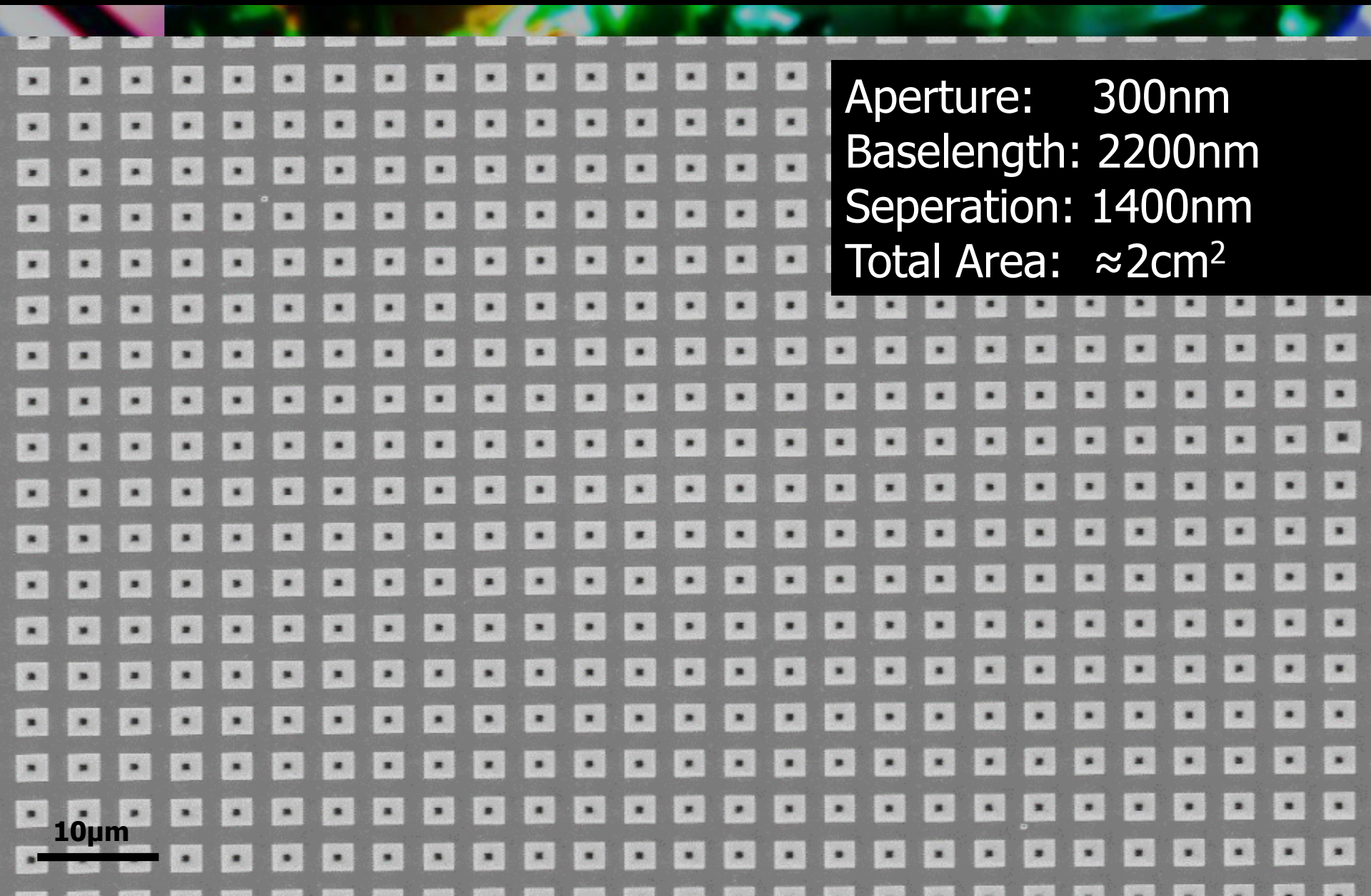
Tipless pyramids



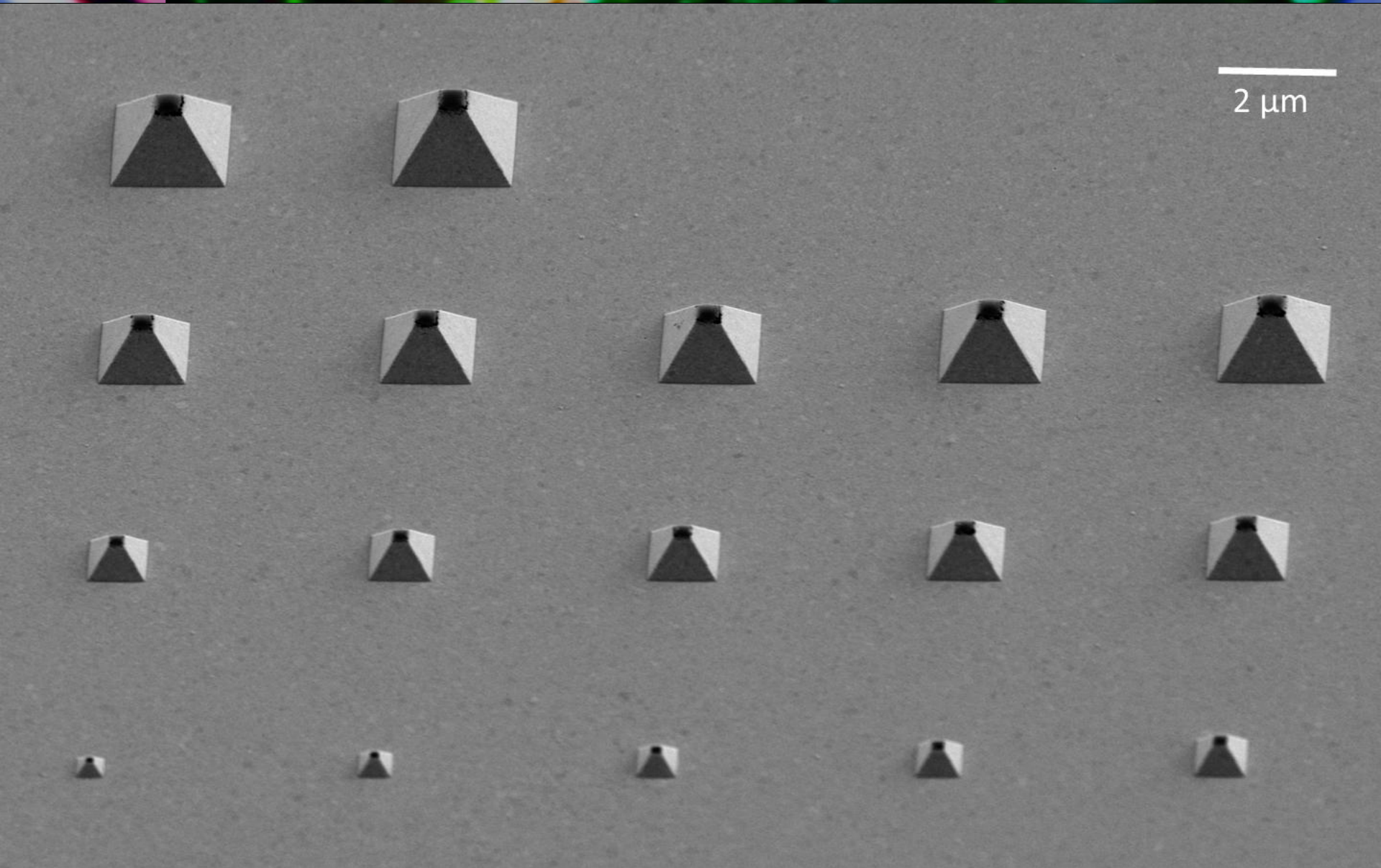
Fabricated substrates



Large-scale fabrication with photolithography



Different aspect ratios



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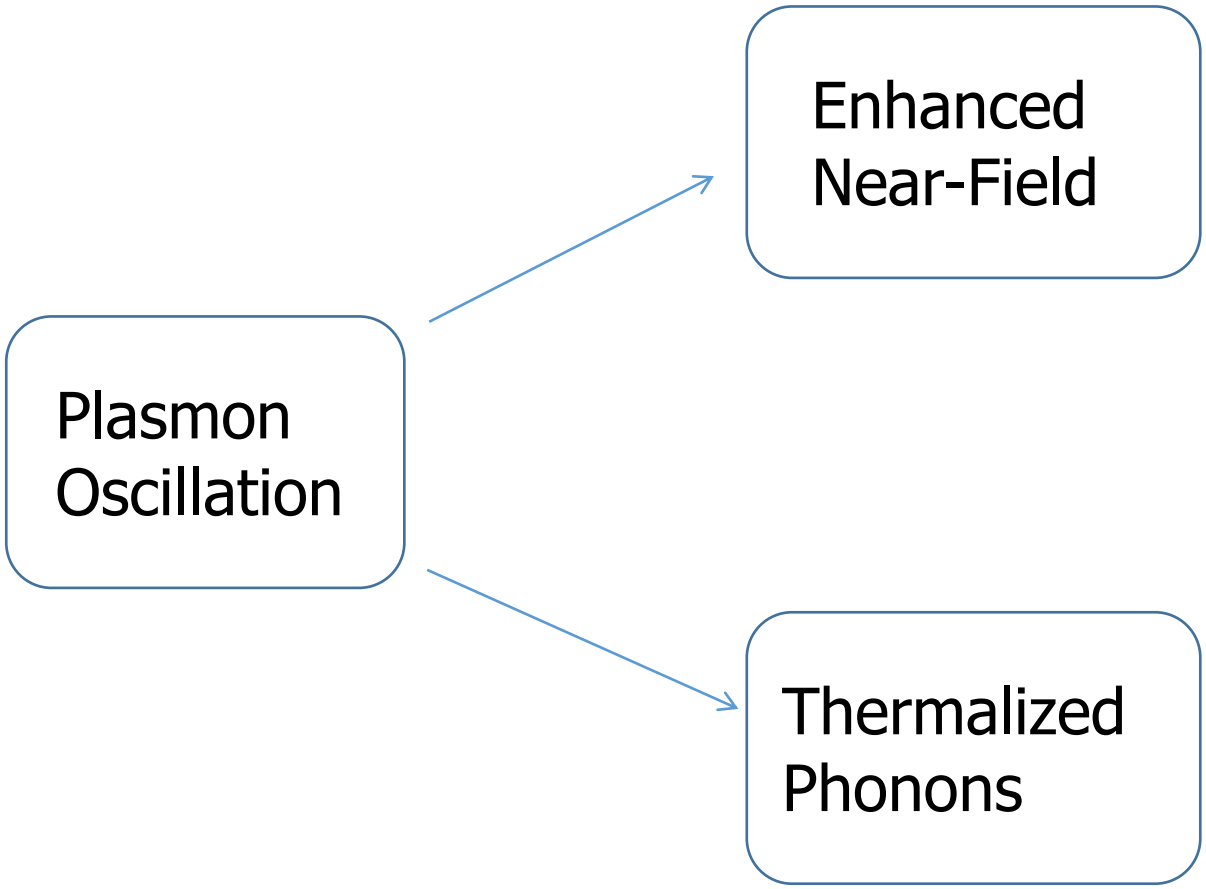
2. **Adjustable ☑**
3. Strong Plasmonic Effect for Efficient and Localized Poration
4. Robust/Stable

Outline

Fabrication

Simulation and Characterization

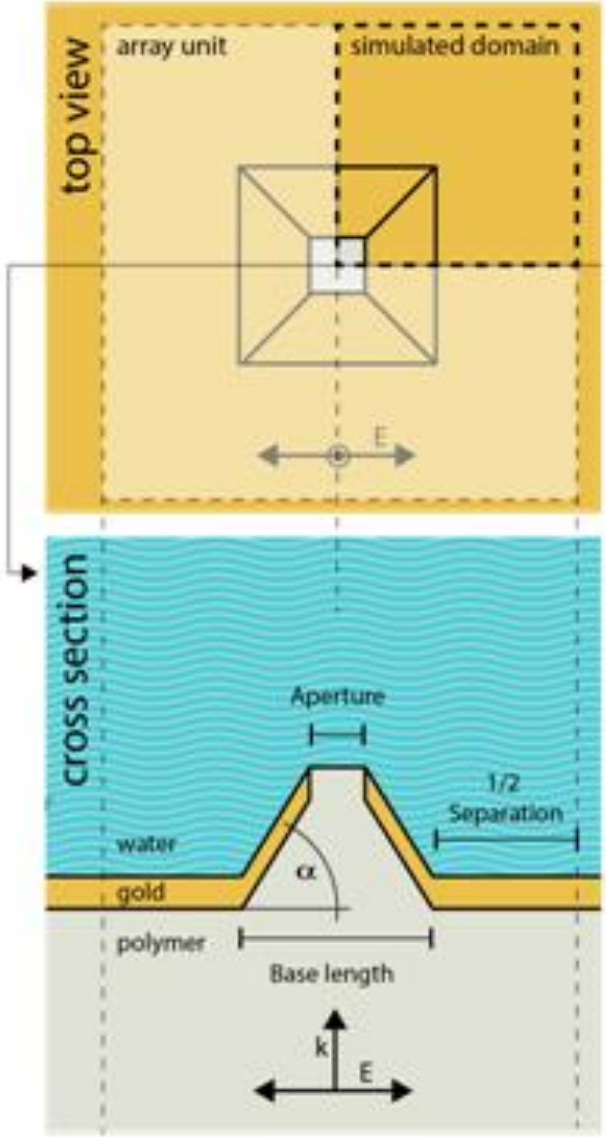
Ultra-short laser excitation of plasmonic structures



Effect on Environment:
- Plasma Generation
- Chemical Damage
- Bond Cutting

Effect on Structure:
- Temperature Increase
- Melting
- Ablation

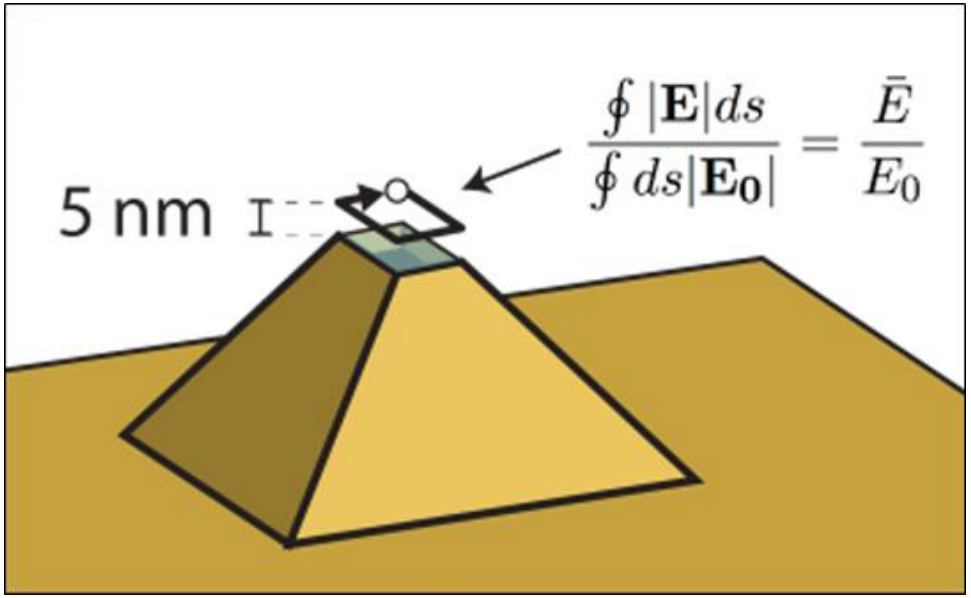
Simulations: Field Enhancement



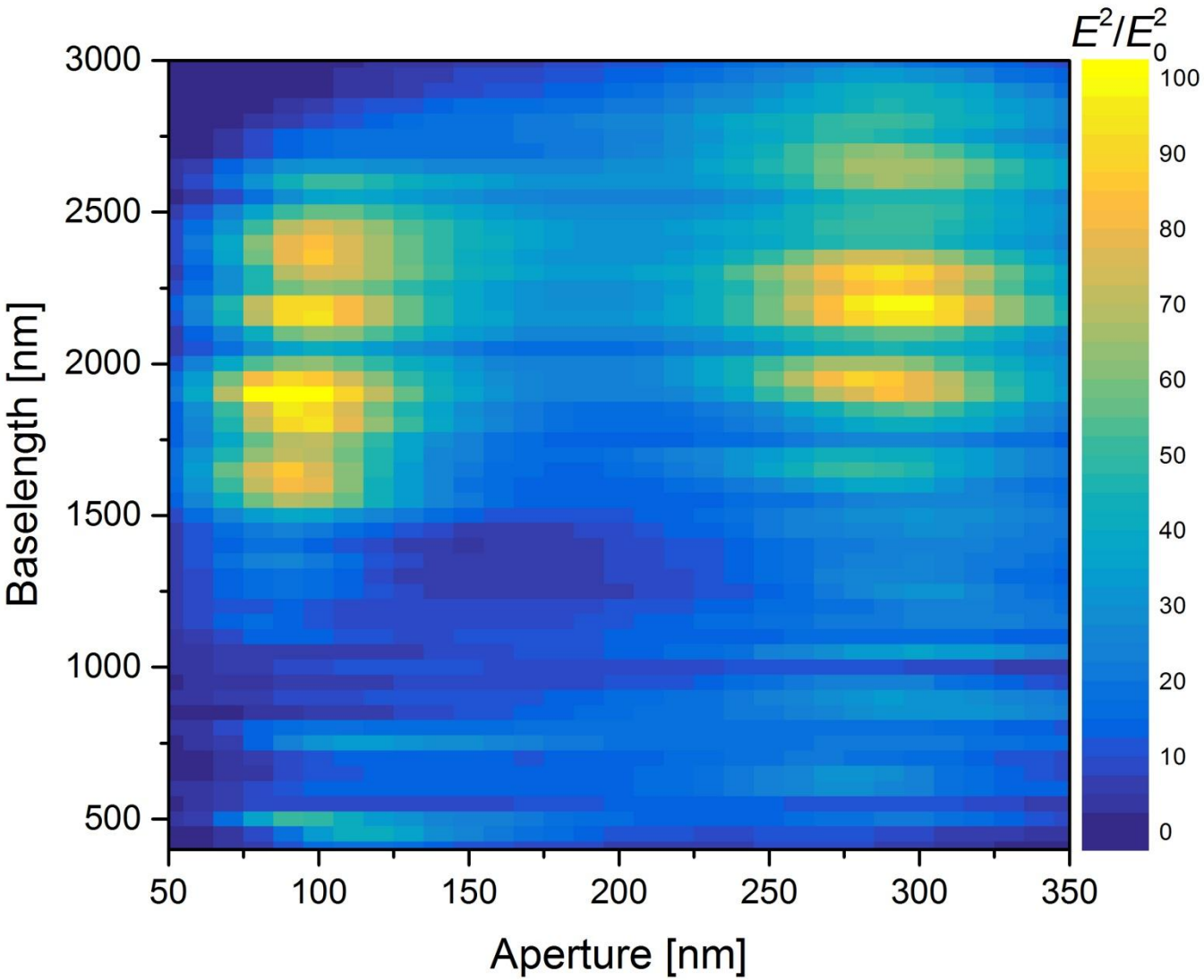
Optimization for 800nm excitation

Geometrical Parameters to Explore:
- Baselength
- Aperture
- Separation

Figure of Merit:
Average Field Enhancement
5nm above the Aperture



Optimization: Field Enhancement



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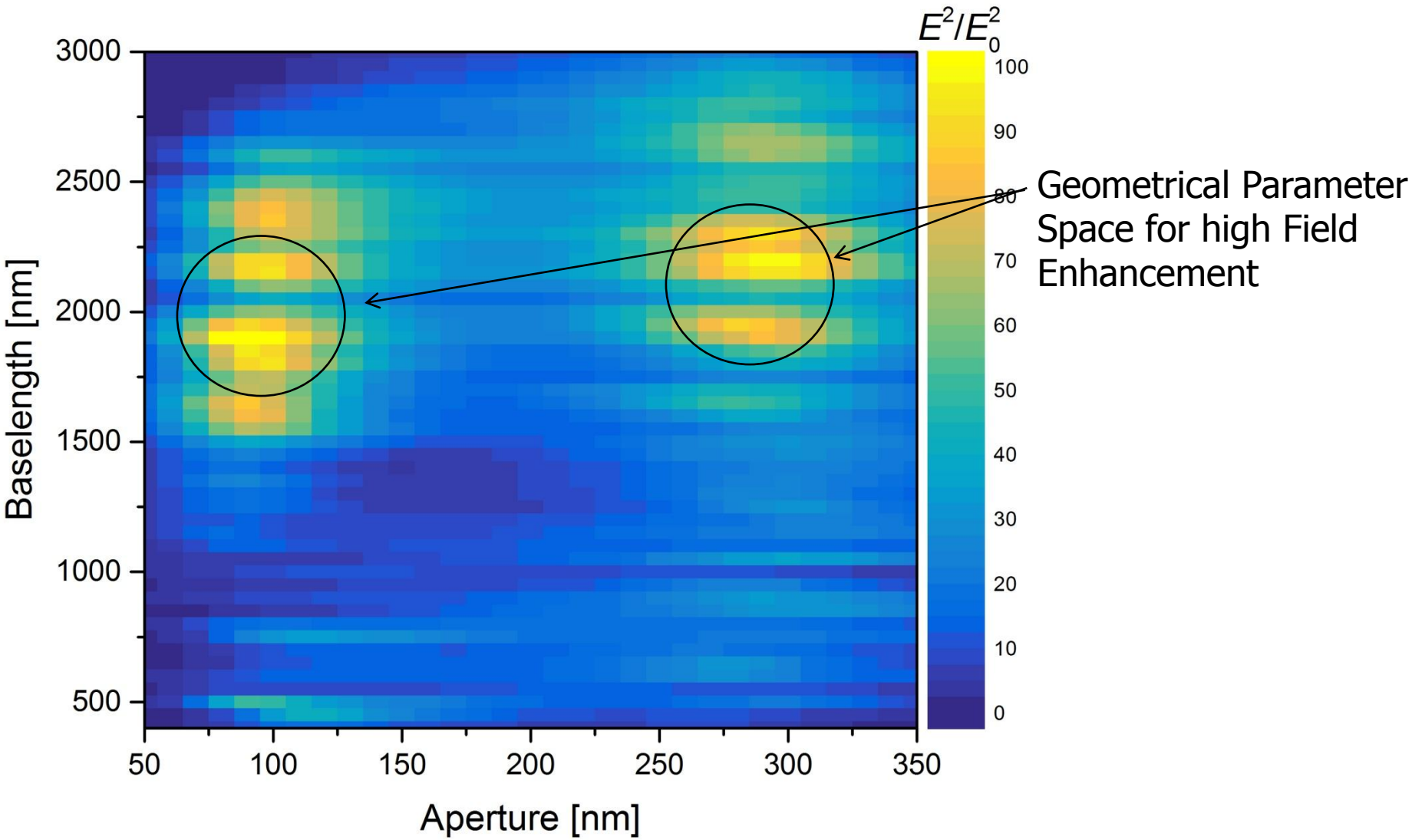
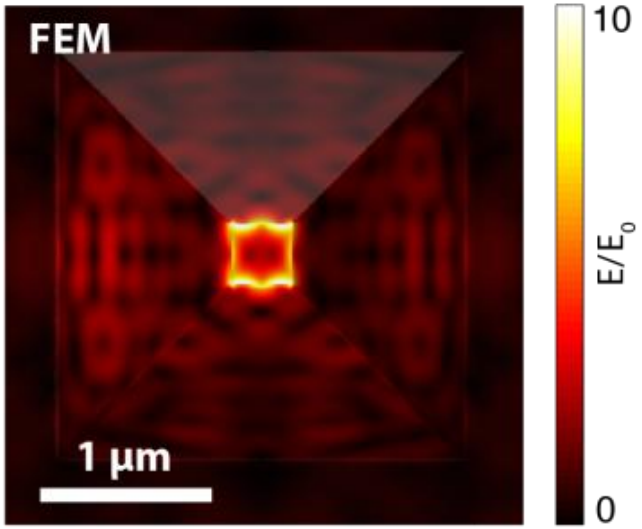


Experiments vs Simulation



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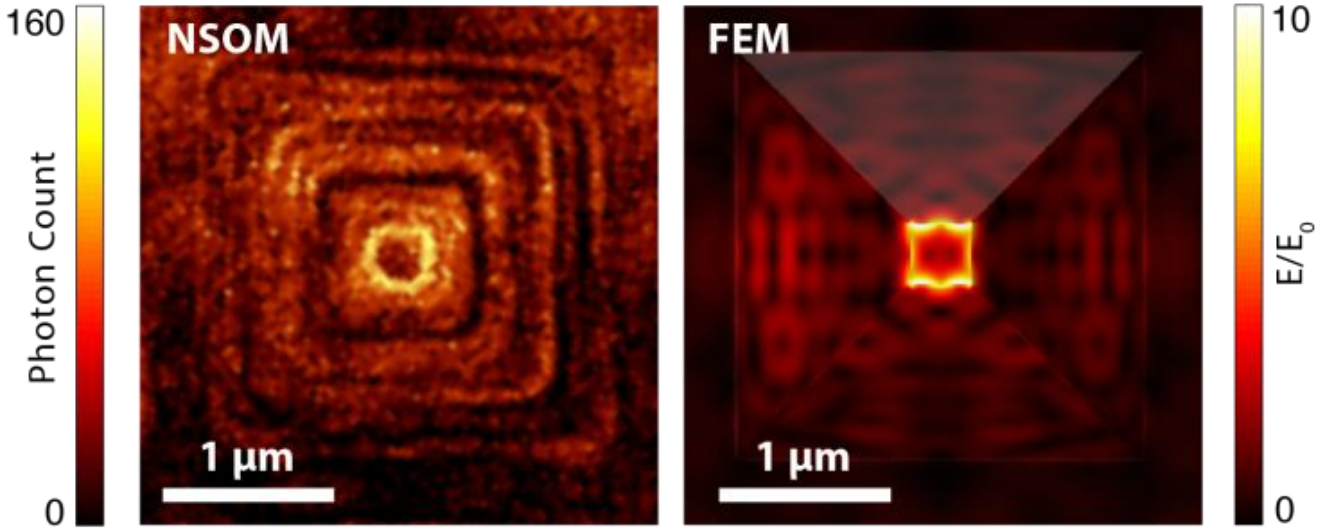
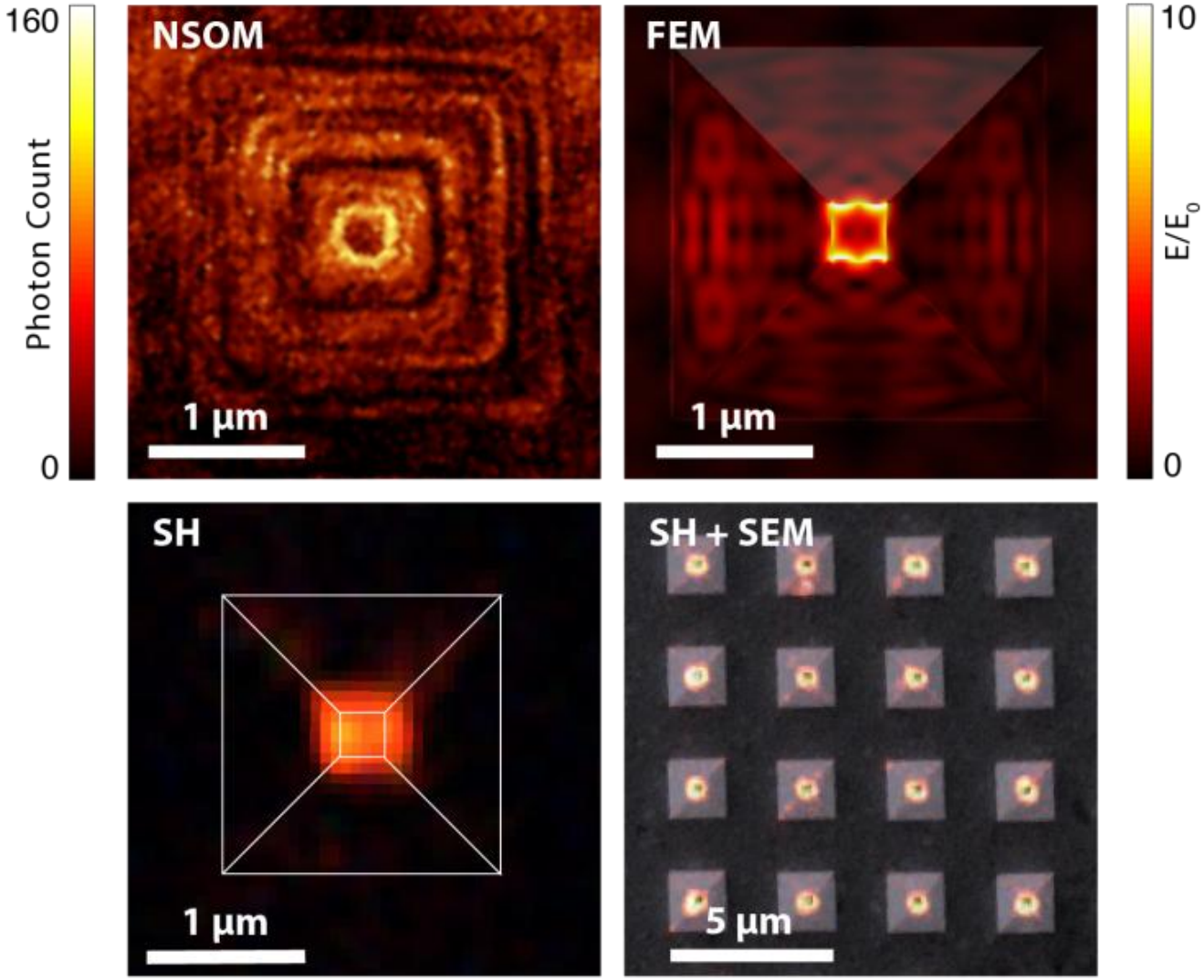
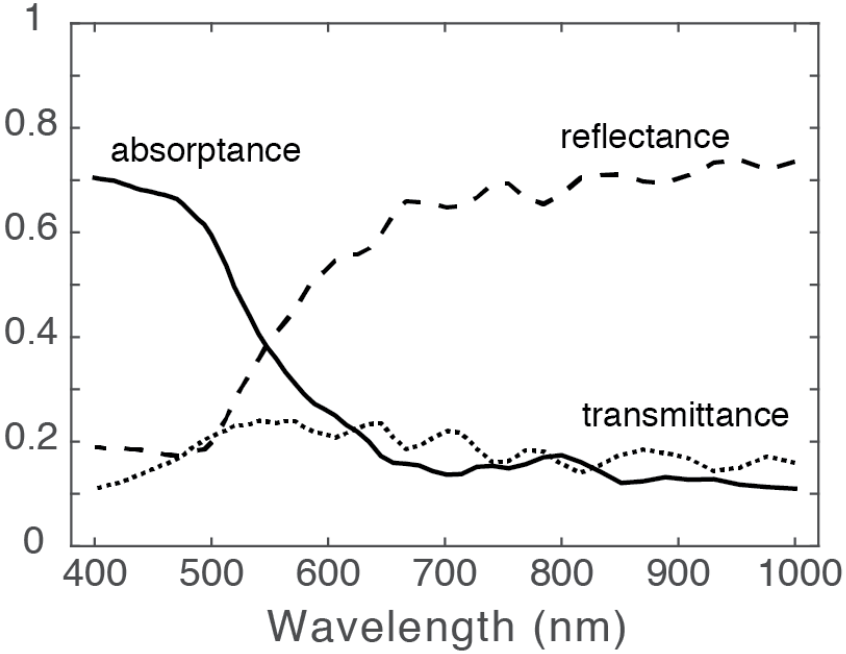


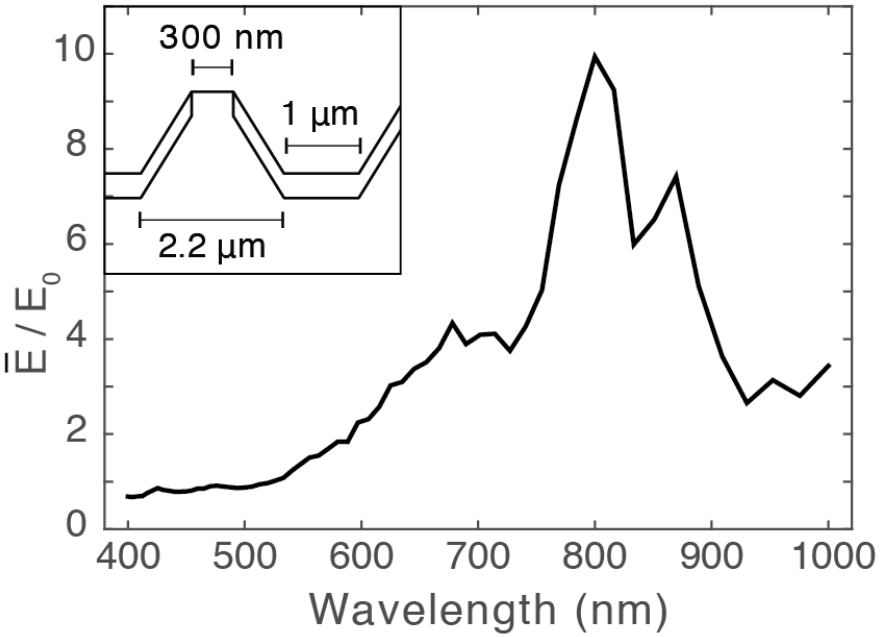
Experiments vs Simulation



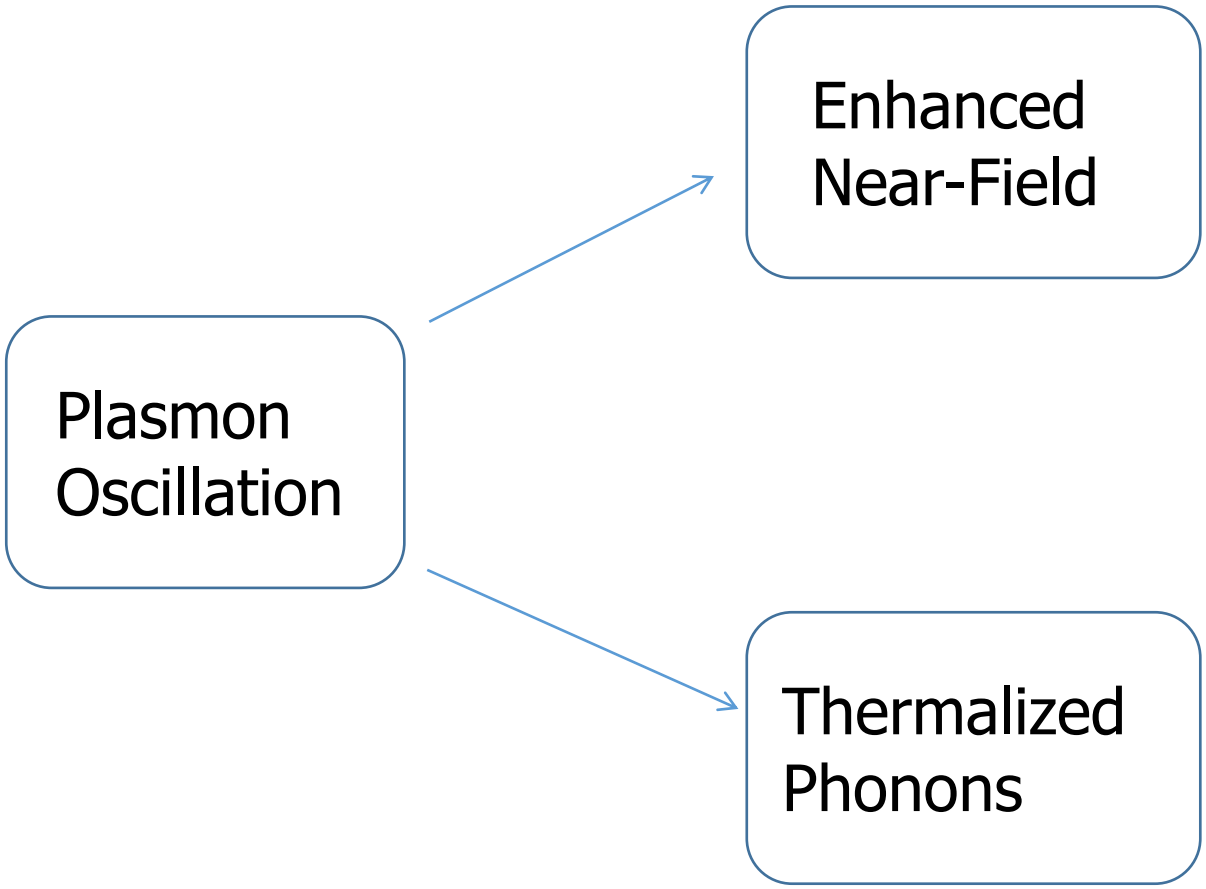
Simulations: Field Enhancement

Low-absorptance regime to avoid thermal damage of the structure





Ultra-short laser excitation of plasmonic structures



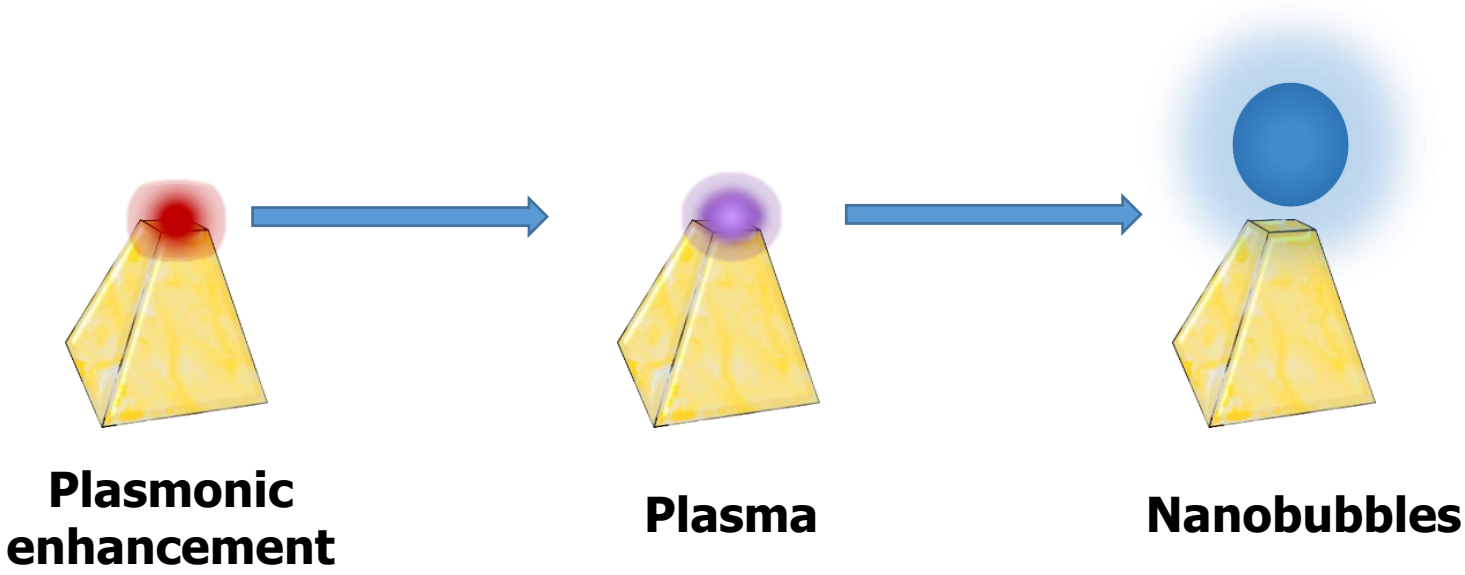
Effect on Environment:

- **Plasma Generation**
- Chemical Damage
- Bond Cutting

Effect on Structure:

- **Temperature Increase**
- Melting
- Ablation

Plasma-mediated bubble formation

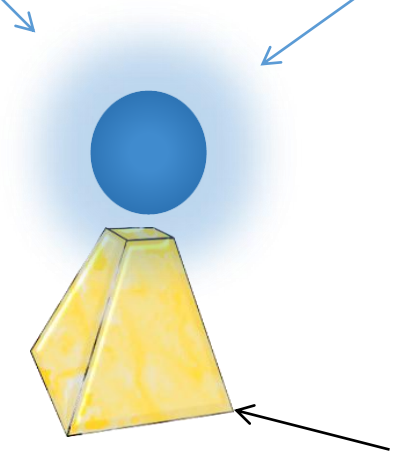


Plasma-mediated bubble formation

Electron Density:
$n_e > n_{crit} = 10^{21} cm^{-3}$

Critical Temperature for Bubble Formation:
$T_w > 0.85 x T_{crit} = 550$ K

Energy Density:
$u_e > u_{crit} = 551$ Jcm^{-3}



Melting Temperature of Bulk Gold:
$T_m = 1337$ K

Mechanisms of femtosecond laser nanosurgery of cells and tissues Vogel et al. Appl. Phys. B: Lasers Opt. 81 (2005) 1015–1047.
Plasmonics for pulsed-laser cell surgery: Fundamentals and applications *E. Boulais et al. Journal of Photochemisty and Photobiology C: Photochemistry Reviews 2013*

Plasma Formation

Wavelength:	800nm
Pulse length:	100fs
Fluence:	$10mJ/cm^2$
Baselength:	1800nm
Aperture:	300nm
Gold Layer:	50nm

Plasma Formation

Wavelength: 800nm
Pulse length: 100fs
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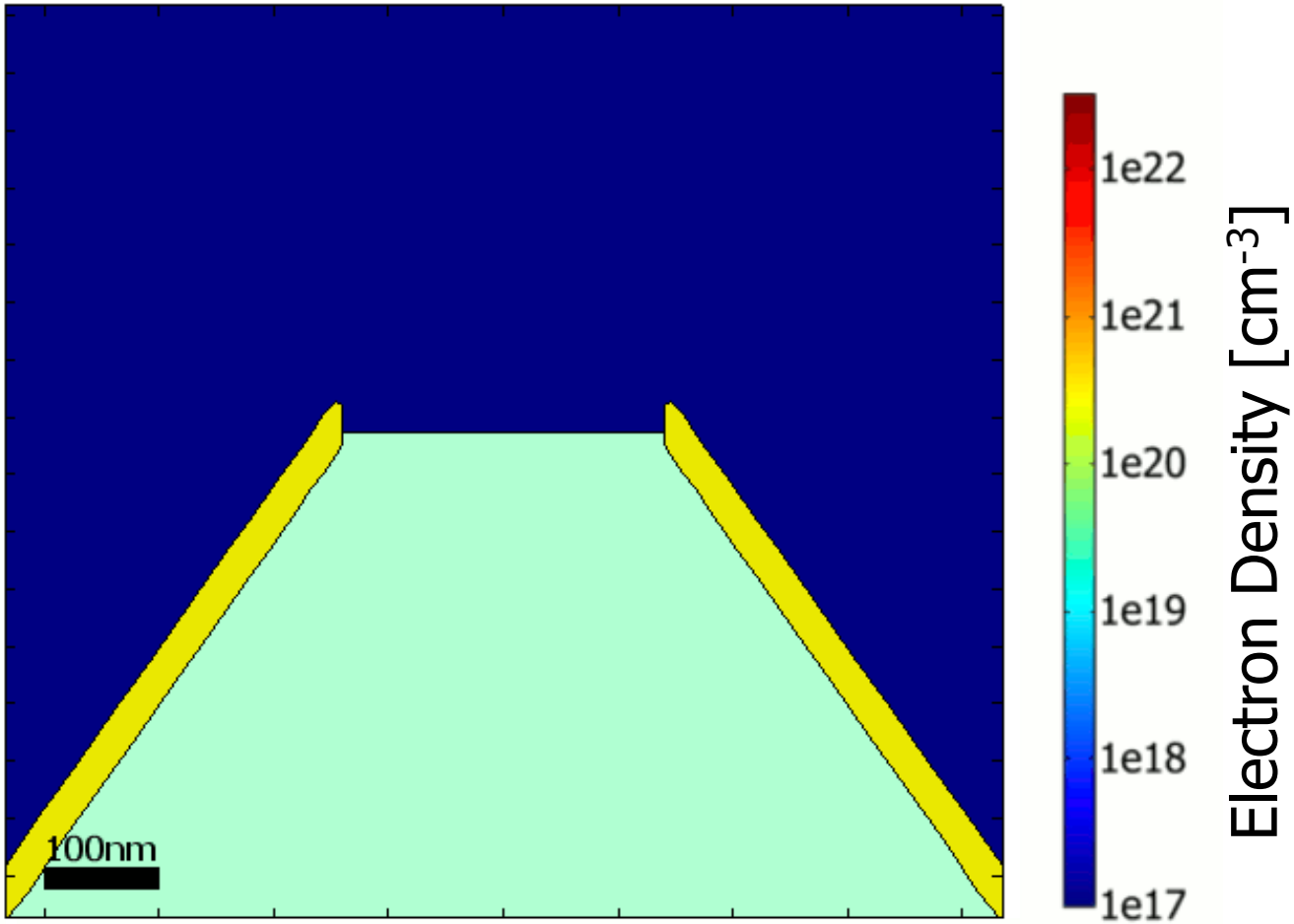

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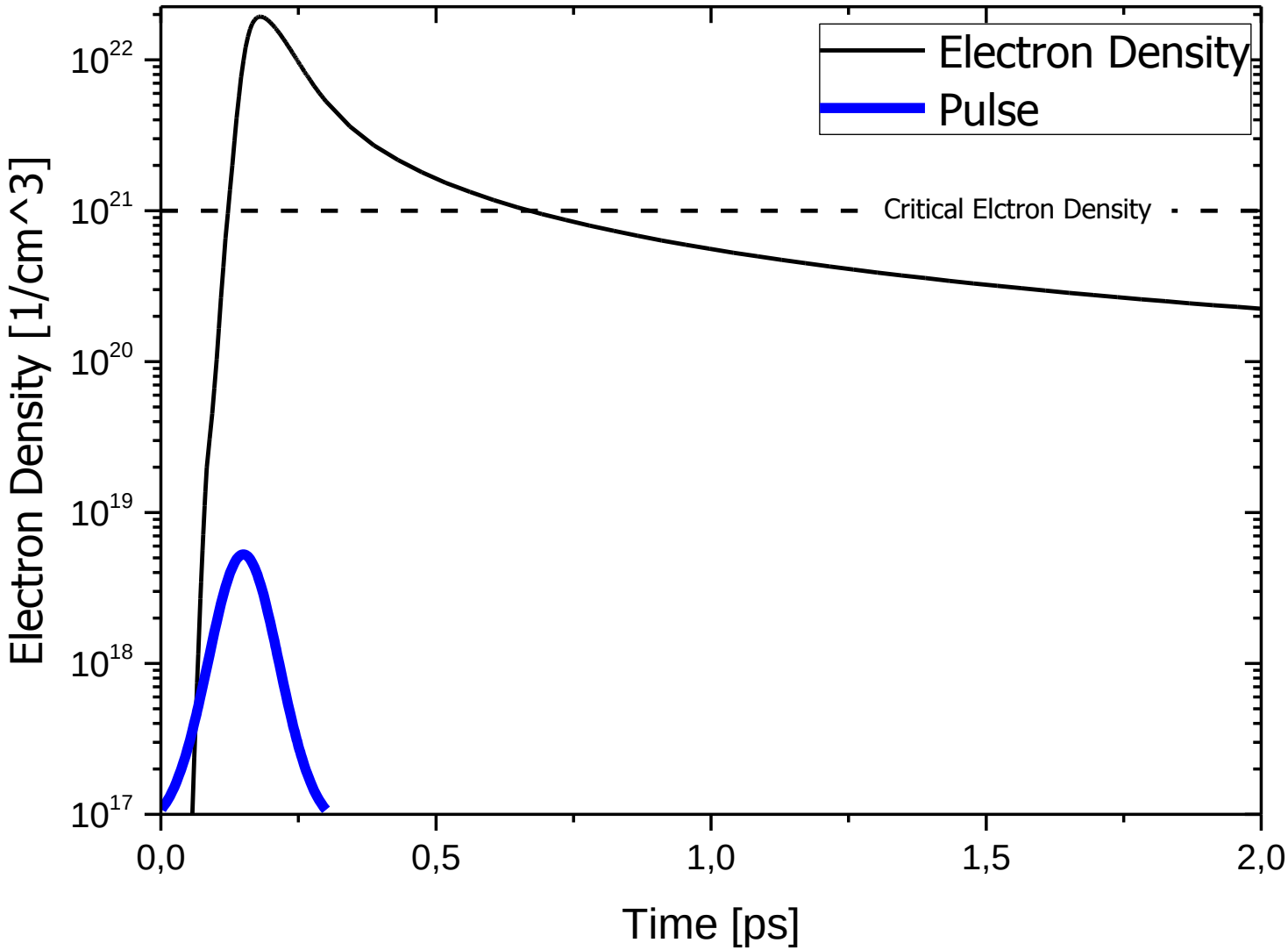

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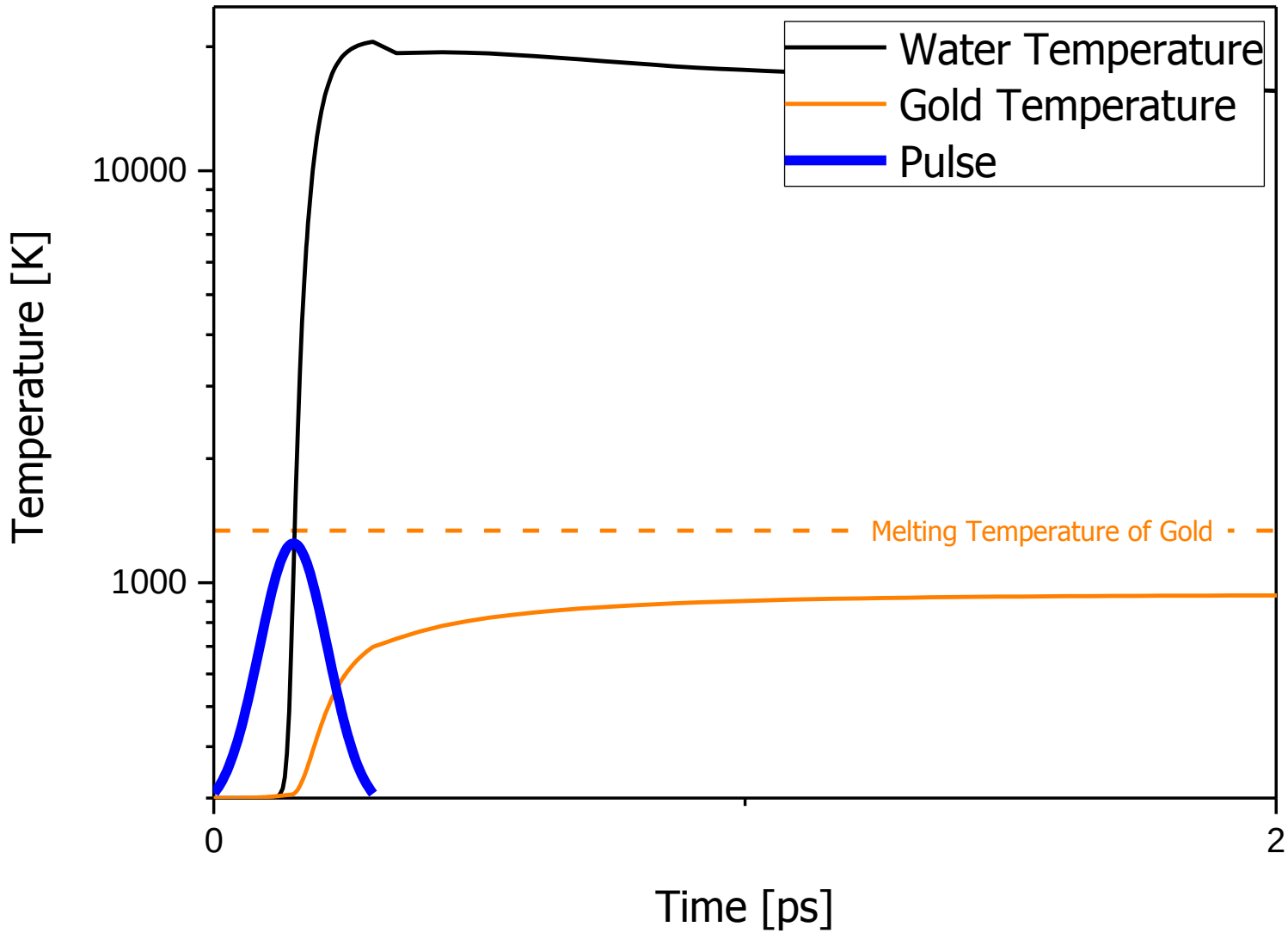

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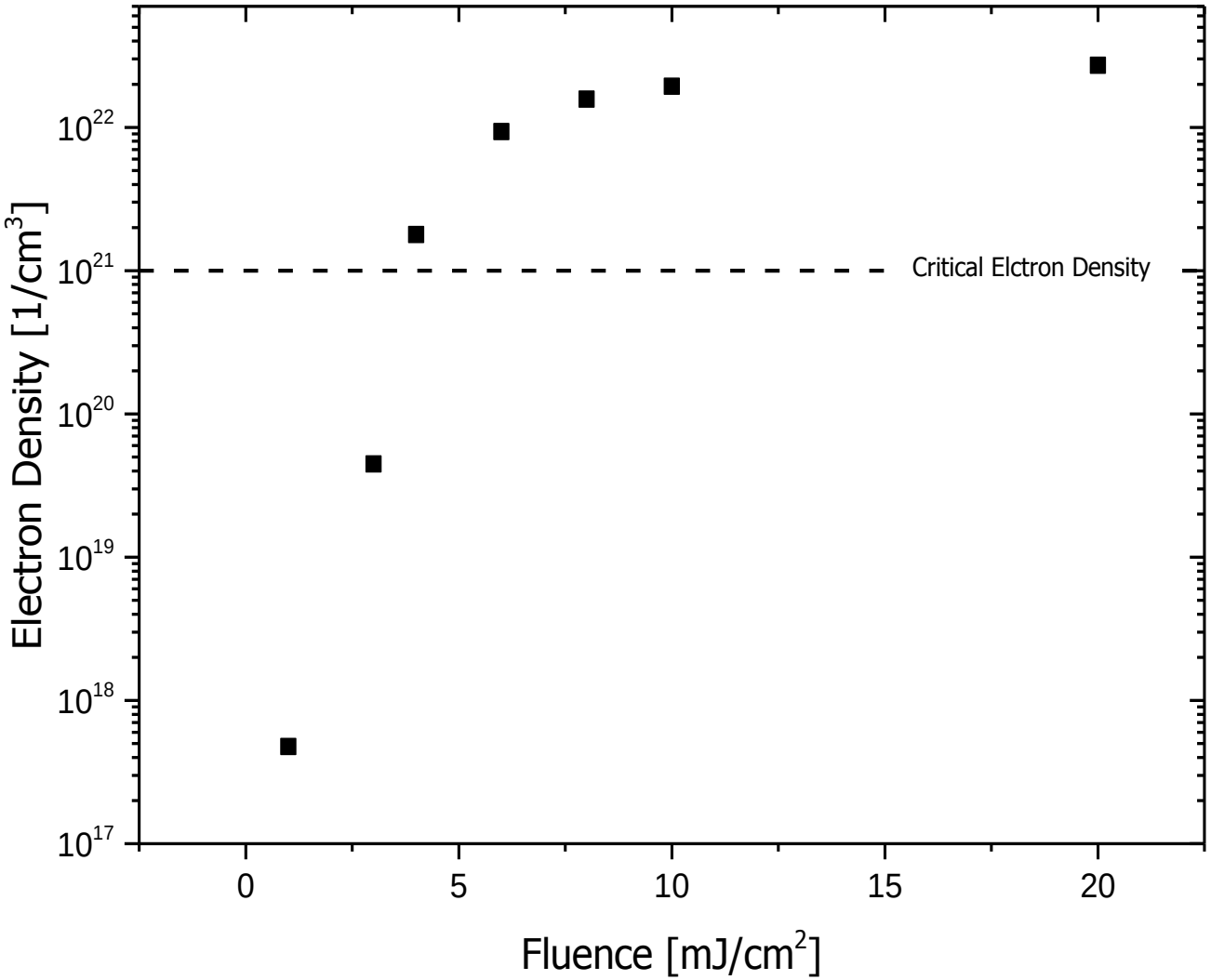

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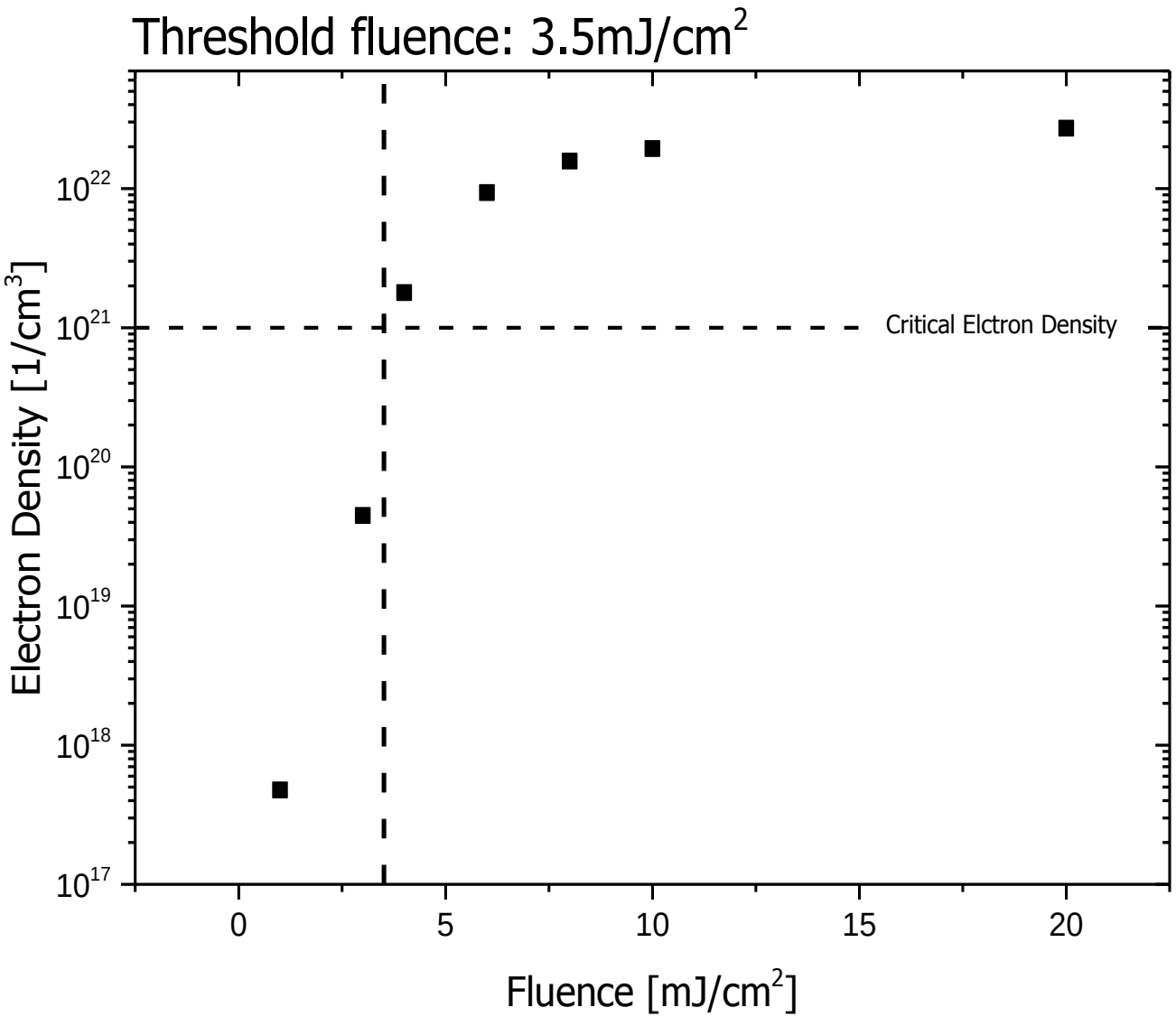
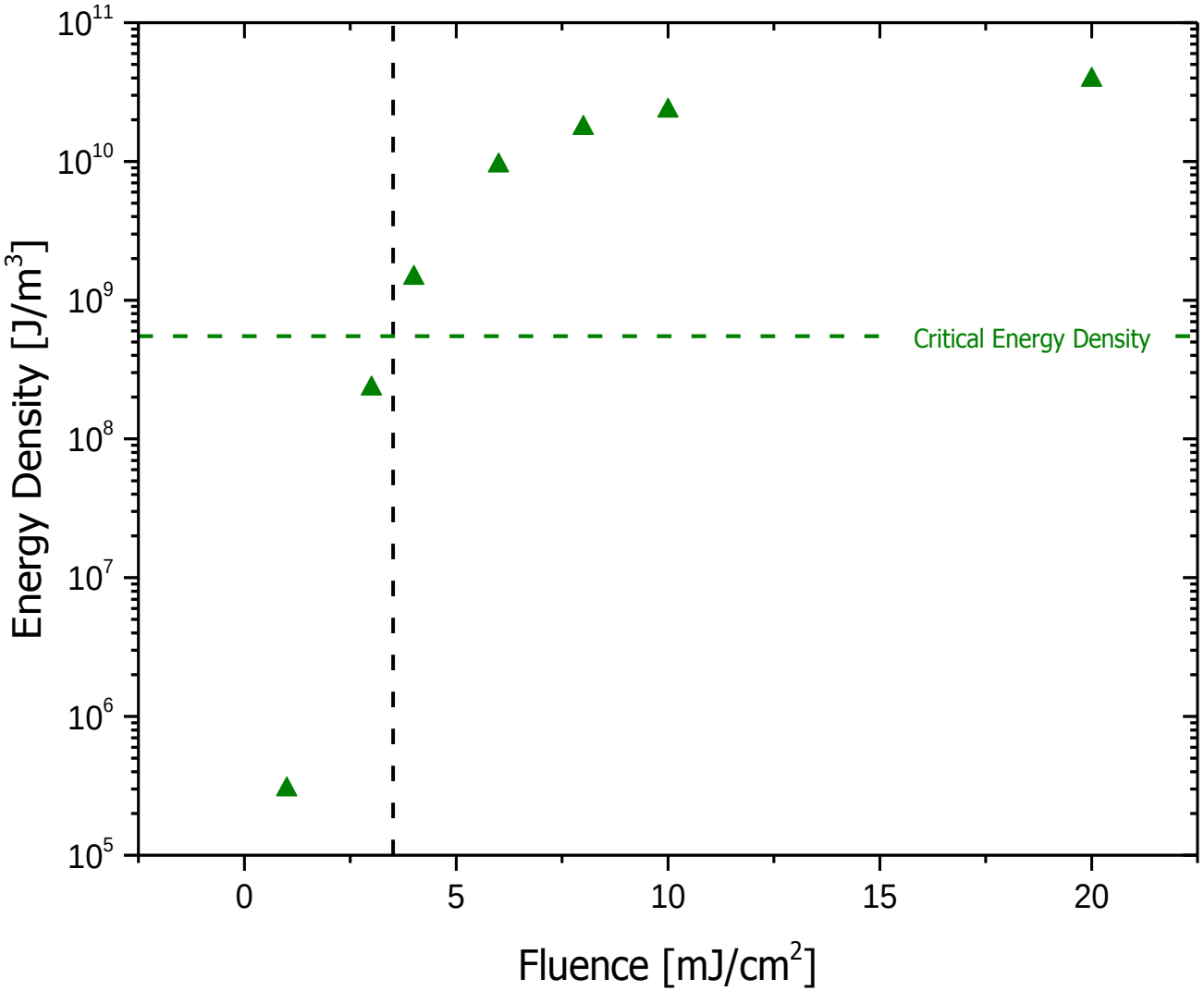


Plasma Formation



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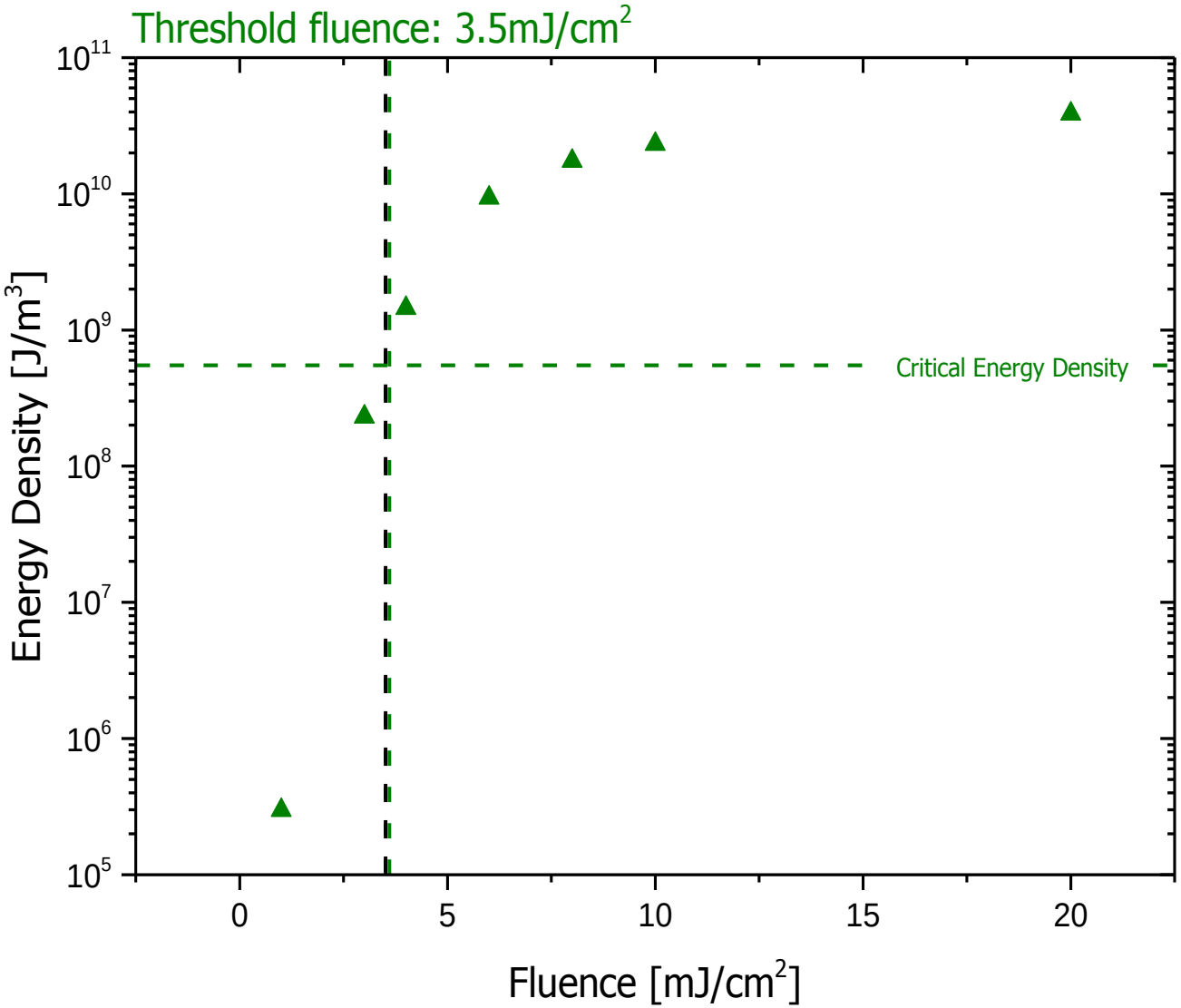

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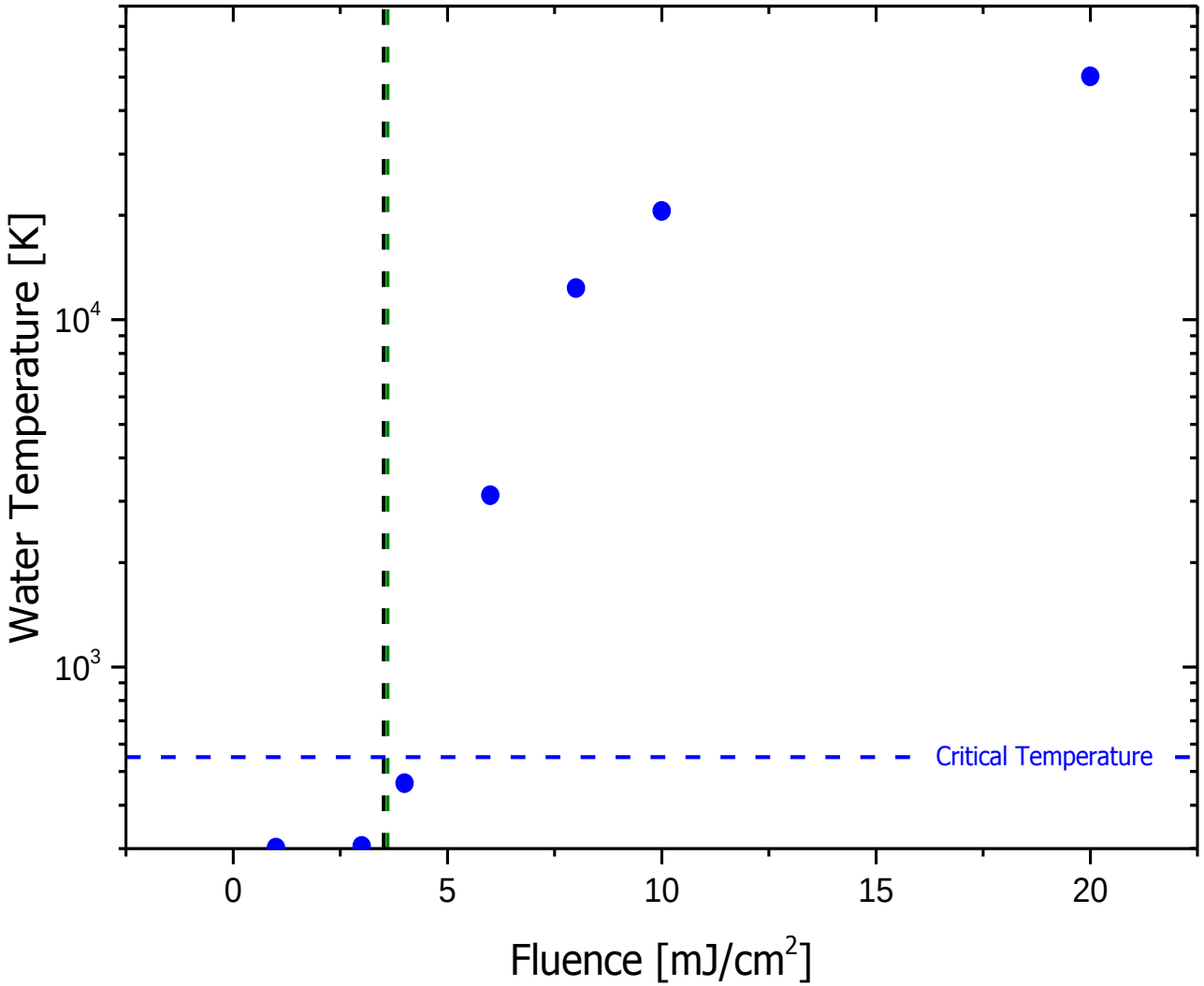
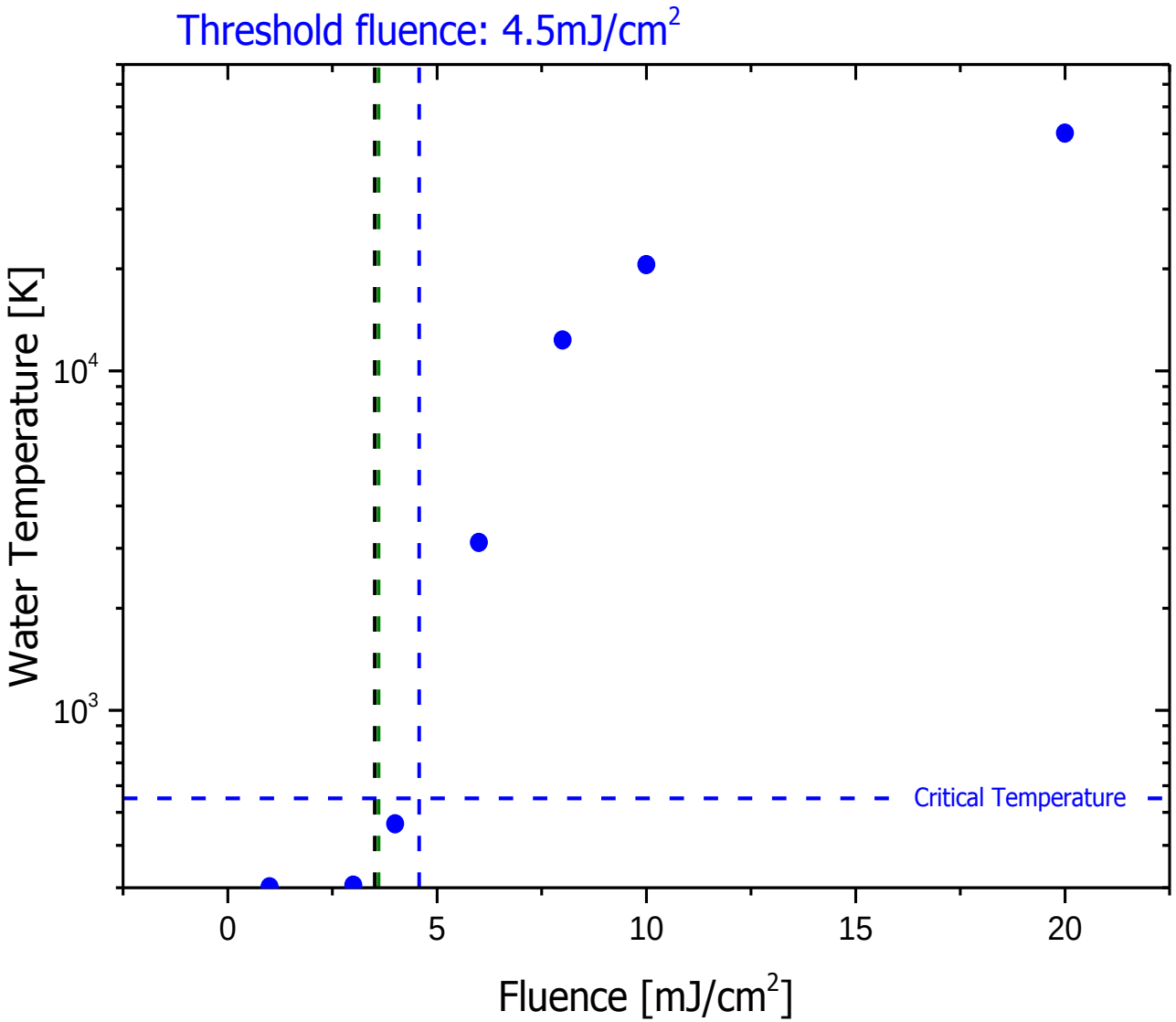


Plasma Formation



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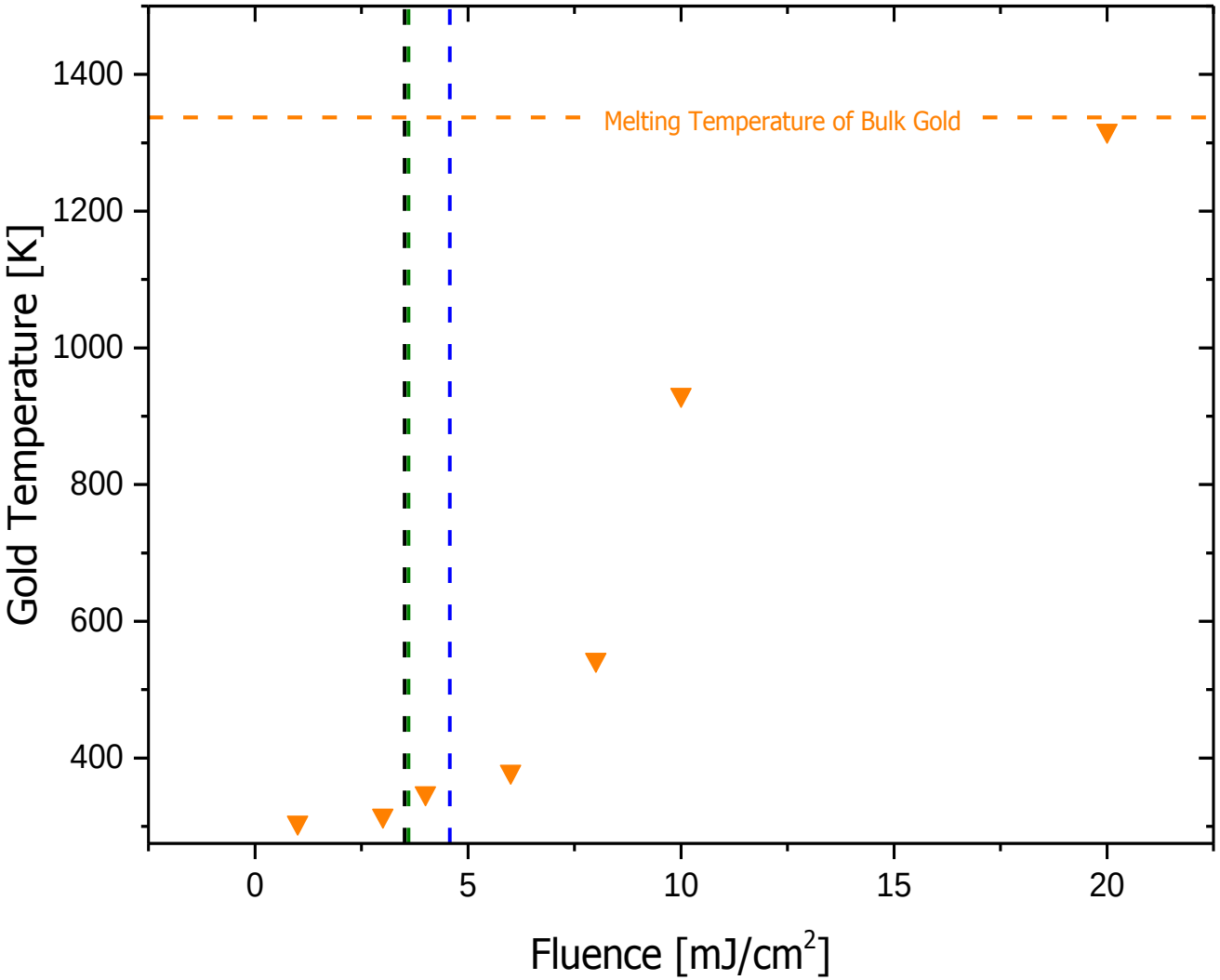

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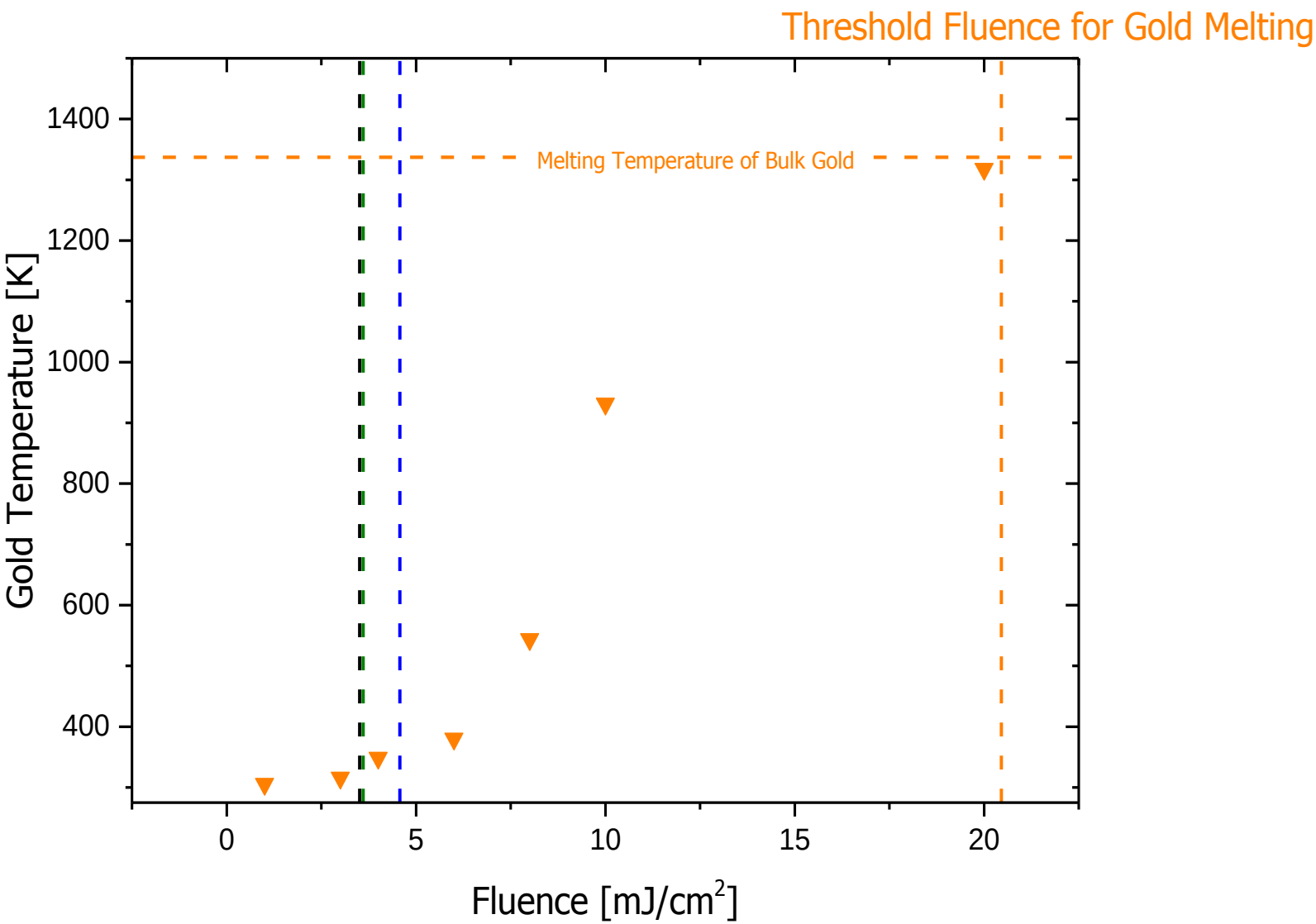

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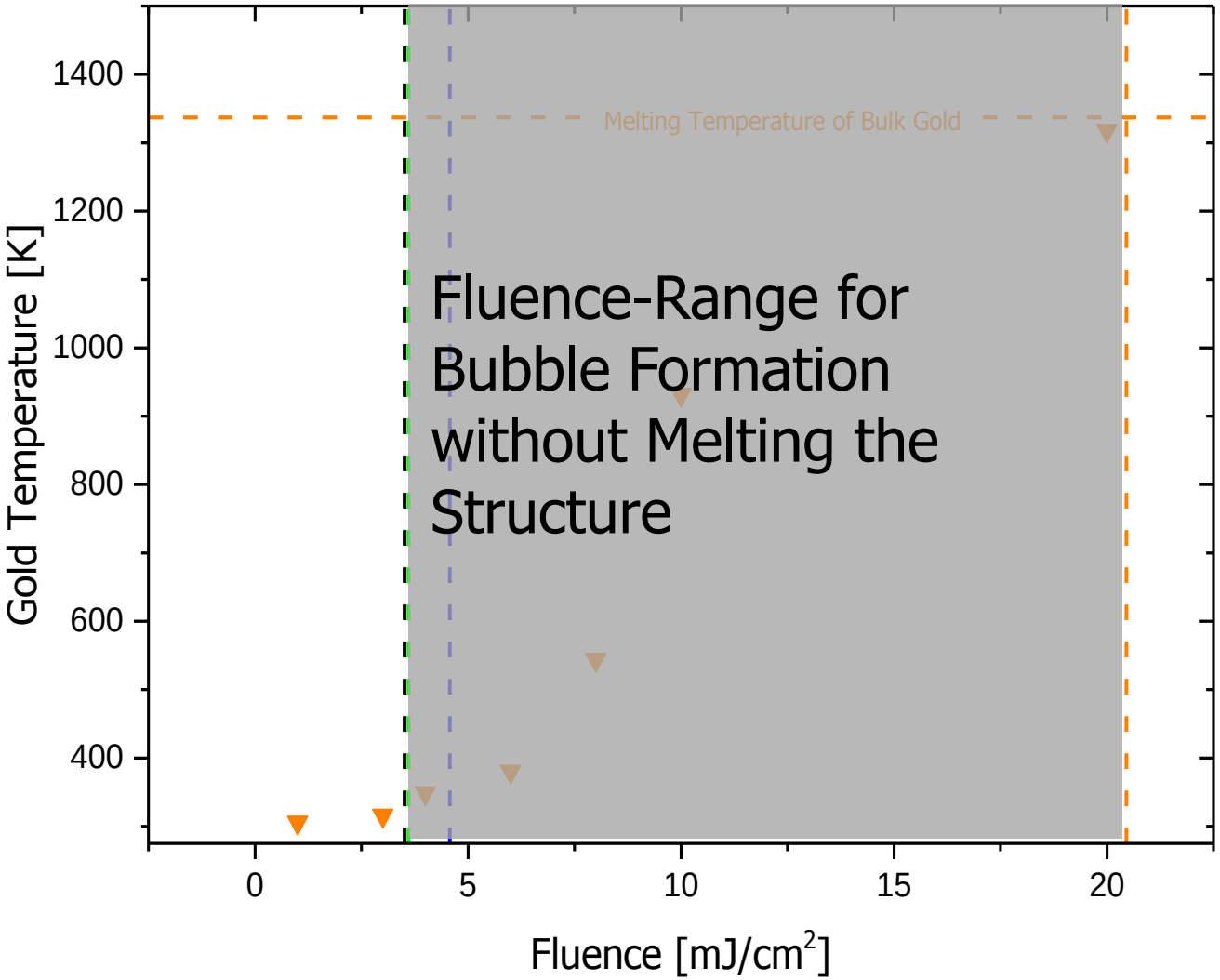


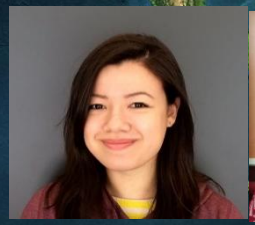
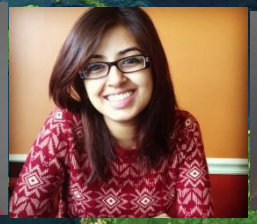
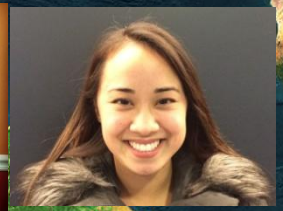
Design Aspects

1. **Easy to Fabricate/Large-Scale-Fabrication ☑**
2. **Adjustable ☑**
3. **Strong Plasmonic Effect for Efficient and Localized Poration ☑**
4. **Robust/Stable (Theoretical) ☑**

Acknowledgements

Harvard University

Eric Mazur

Daryl Vulis | Nabiha Saklayen | Marinna Madrid

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Sebastien Courvoisier

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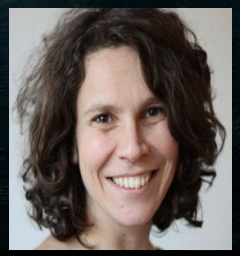

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