Berner Fachhochschule
Haute école spécialisée bernoise
Bern University of Applied Sciences

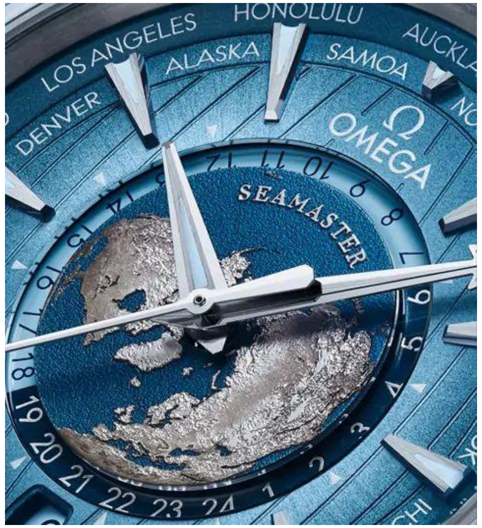
Plasmonic Coloring of Noble Metals by Direct Laser Marking

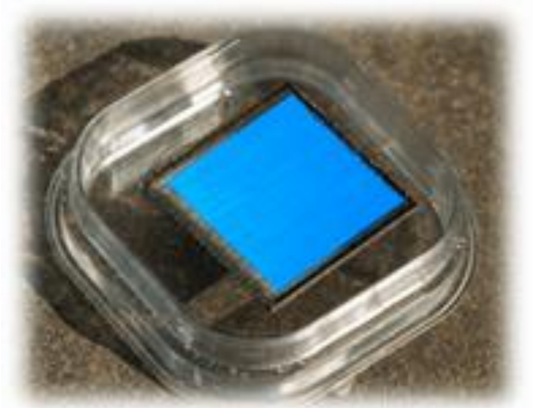
Rainer Kling, Simon Walker, Stefan Remund, Beat Neuenschwander

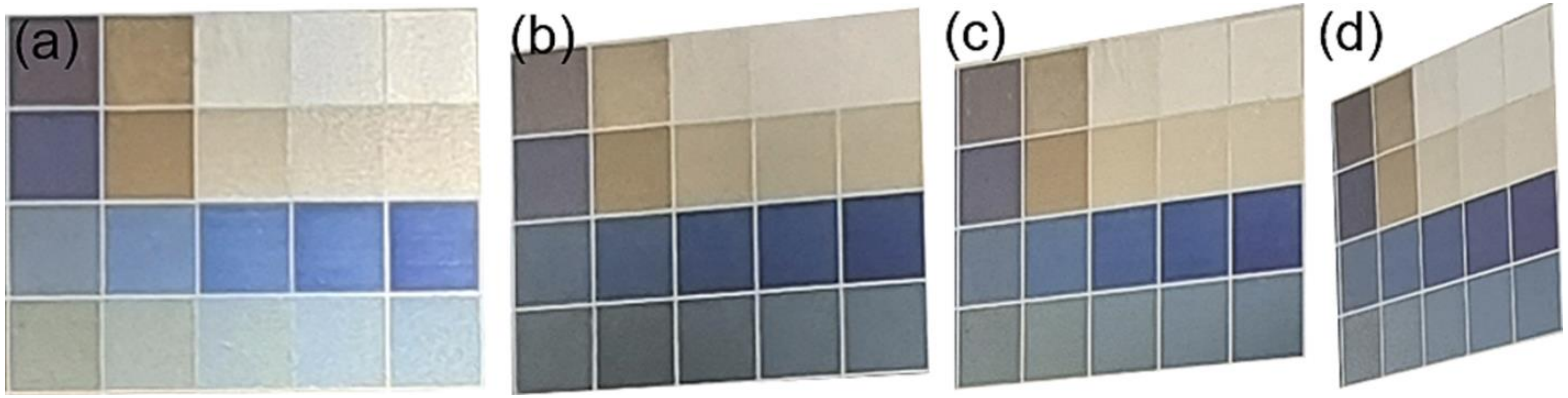
- Institute for Applied Laser, Photonics and Surface Technologies ALPS

Motivation for Plasmonic Colors

- Watches and Silver Coins
- Metal coloring works on stainless steel, titanium, aluminum
- Oxide layer thickness determines color
- Most laser-colored surfaces are angle-dependent







Array of colours by laser colouring on stainless steel. (a) Stainless steel sample at rest position at 0◦; (b) stainless steel sample tilted by 10◦; (c) stainless steel sample tilt

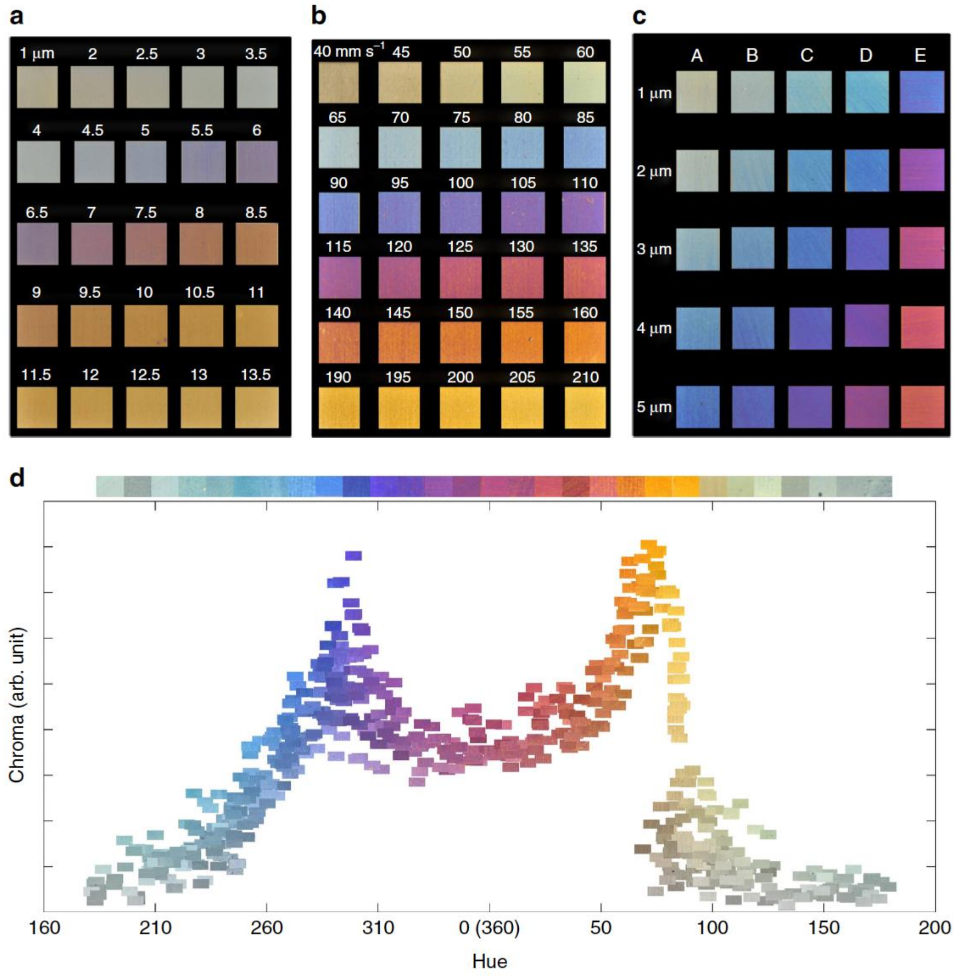
Source: Gaidys et al., Optics & Laser Technology 174 (2024) 110561

Obtainable Color Spectrum in Silver

- The creation metal NPs for surface coloring has attracted considerable interest

- Guay et al results from 2016:

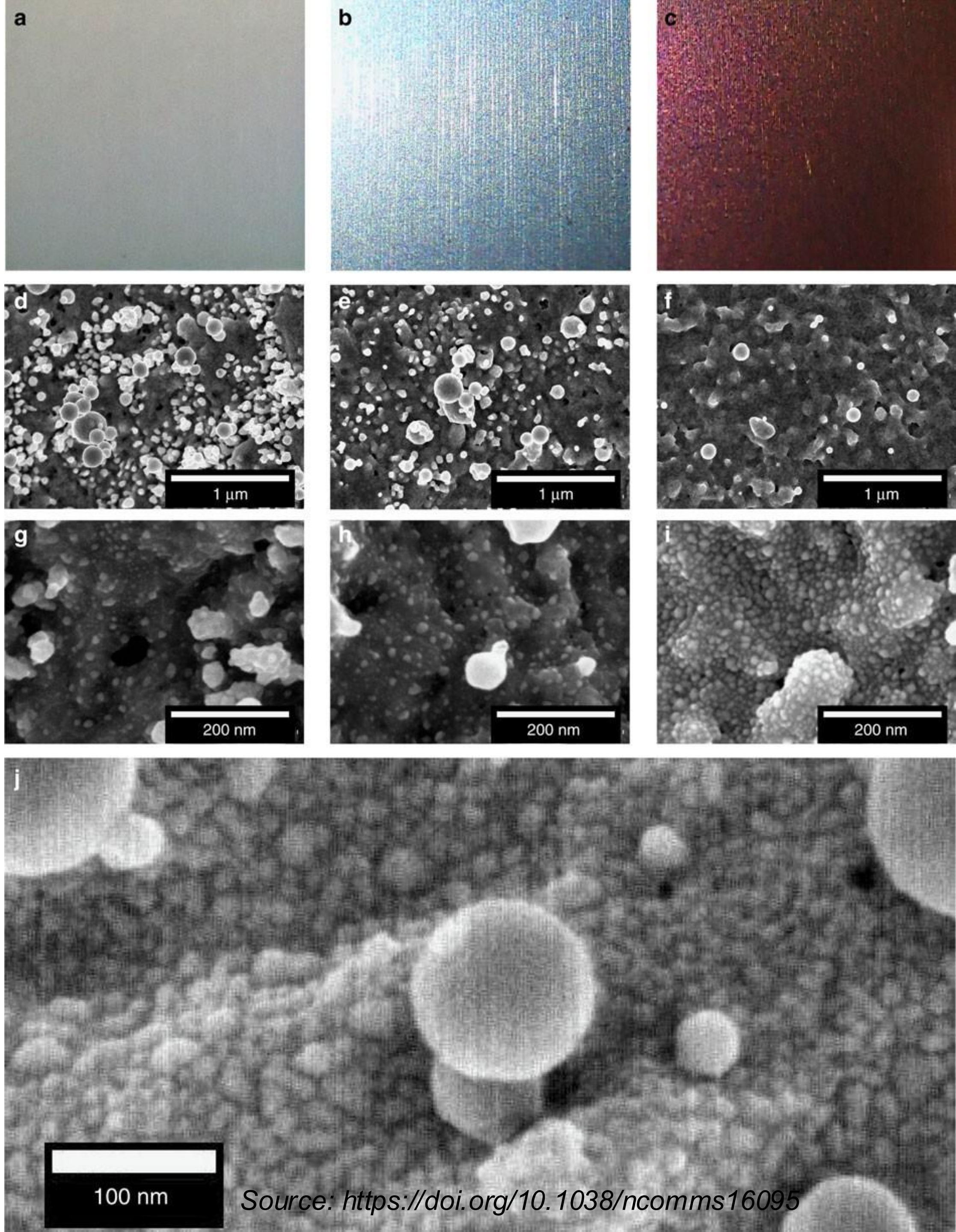
- A: non-burst mode
- B: burst mode
- C: variation of line spacing and hatch
- D: obtainable hue and chroma values



Source: https://doi.org/10.1038/ncomms16095

The burst mode effect on NPs

- First pulse basically ablates material (low to no recast)
- 2nd pulse in burst pushes back particle plume to form NPs on surface
- Balance of pulse energy and pulse overlap controls size, embedding and density of NPs on surface
- NPs are a necessary but not sufficient condition for surface coloring



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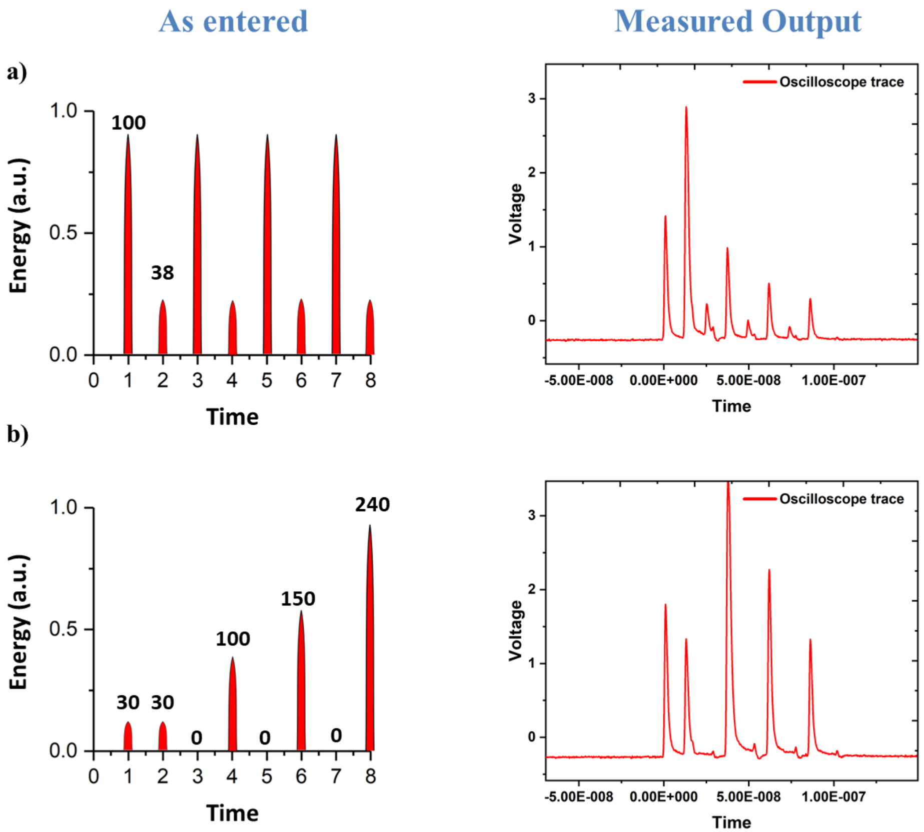
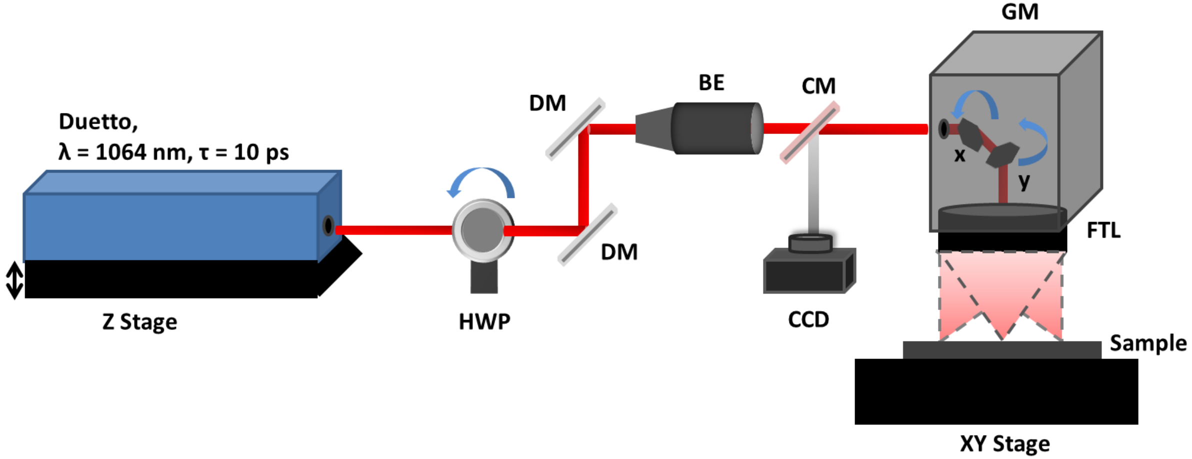
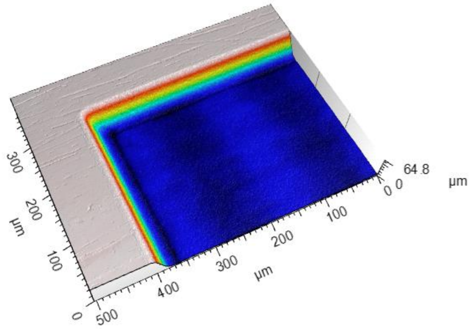
Setup for trials - Burst Pattern

- Creation of metal NPs for surface colourization by picosecond laser pulses
- In burst mode most efficient pattern for colors on silver, gold, etc.





Protocol



- Squares of side length $s = 3mm$ (Ag) and 5mm (Cu) machined with fine variation of spot and line distance $p_x = p_y = 1 - 20\ \mu m$.

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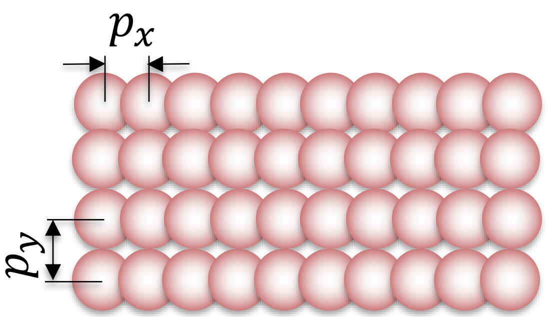
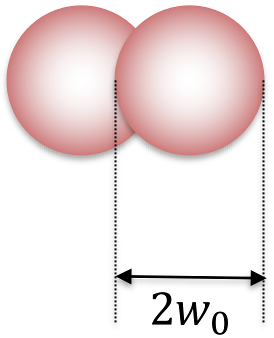
- p_y is also called line distance or line pitch



- We define as overlap O between two pulses:



$$O = 1 - \frac{p_x}{2w_0} \quad \rightarrow \quad \frac{p_x}{2w_0} = (1 - O)$$

- For the marking speed follows:

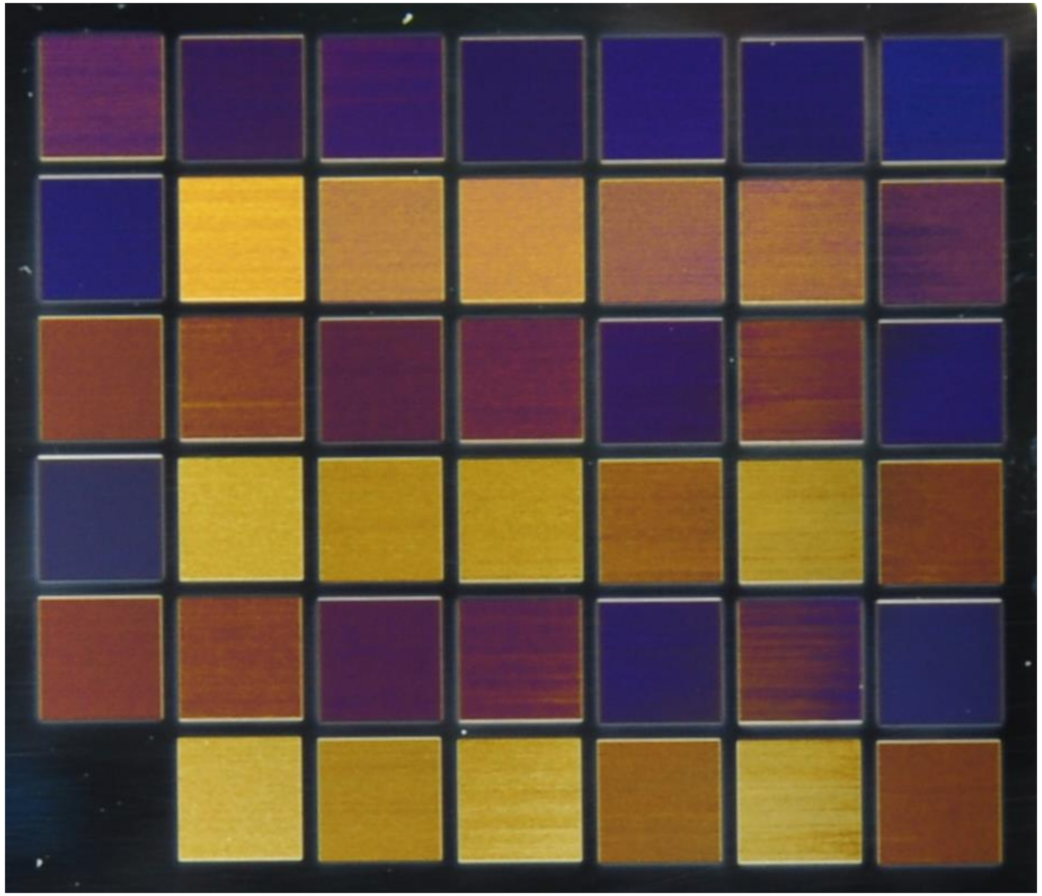
$$v_{mark} = f_{rep} \cdot p_x = 2 \cdot w_0 \cdot (1 - O) \cdot f_{rep}$$

- $p_x = f_{rep} / v_{mark}$

Bulk Silver vs electroplated Silver on Brass

Bulk Silver sample

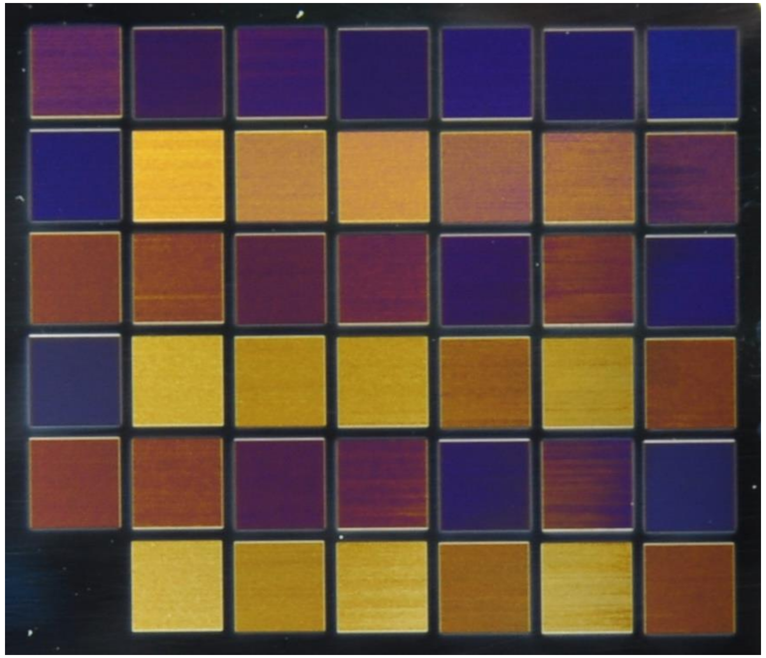
50μm electroplated Silver on Brass



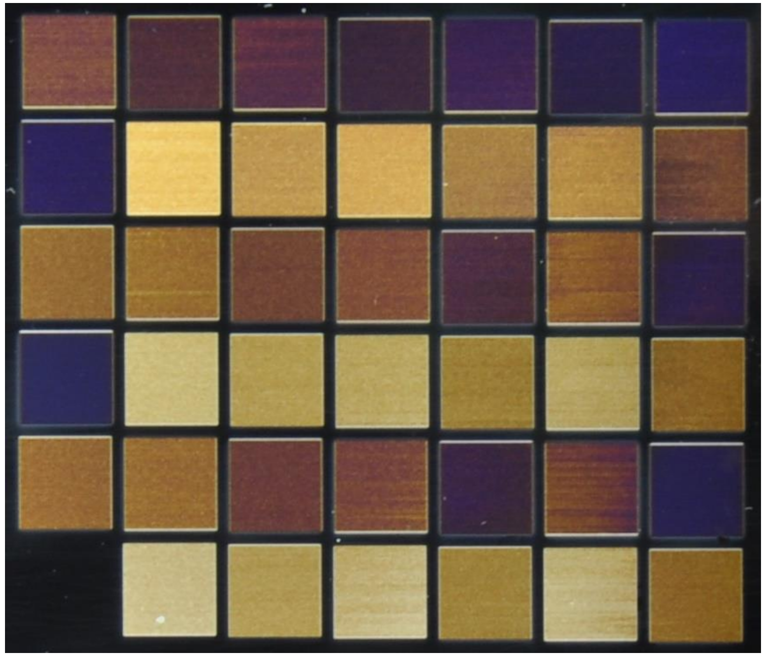
Conclusion: Same Process → Surface quality influences color

Degradation of Electroplated Ag

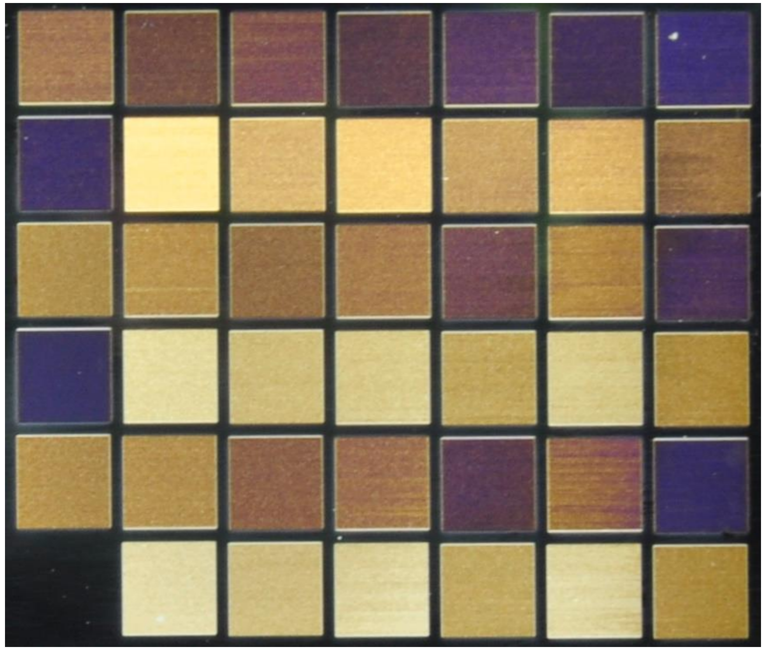
Sample after Processing



1 Week later



2 Weeks later



Conclusion: Same Process → Surface quality influences color degradation

Color palette extension

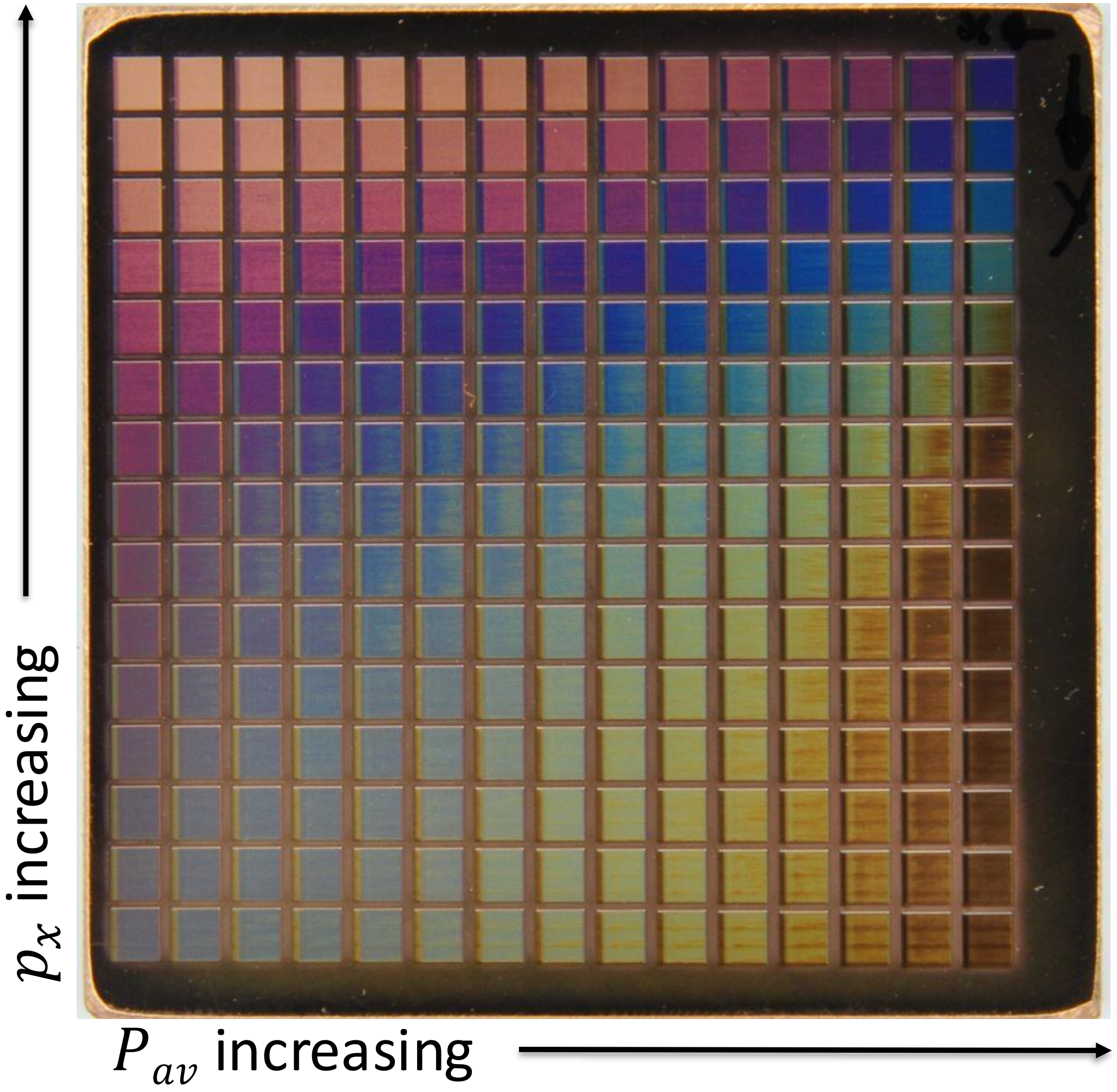
- Colors achieved solely through p_y variation by 0.25μm
- Small change in pulse overlap changes color significantly
- Colors remain stable after 70° ALD coating

Parameters

- p_x =8μm
- P_{av} = 0.484W
- N_{Layer} =5
- f_{rep} = 50kHz
- n_{burst} = 3

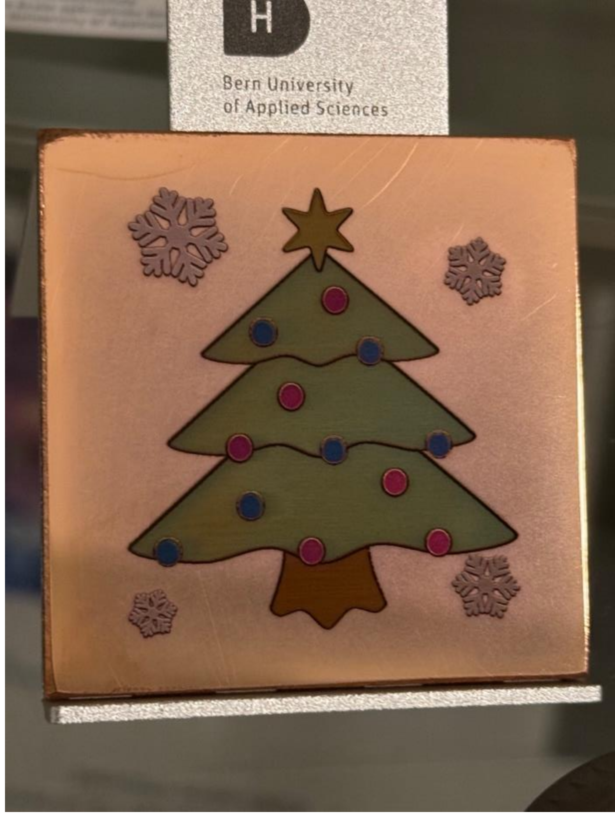
Variation of Fluence and Pitch on Copper

- Double pulses with 25 ns pulse separation provide bright colors
- Small variation in pitch and power provides rich color palette
- Only one layer needed
- Color formation remains stable on copper



Conclusions and Lessons Learned

- Plasmonic colors are generated by a **sensitive interplay** of ablation, NP agglomeration in the plume, redeposition due to burst mode pulses and melt phase generation for embedding the NPs
- Small variation of pulse overlap changes color significantly
- Copper produces nice structural colors, which don't change with time
- ALD layer important for color preservation and scratch resistance



LinkedIn video QR code

Thank you for your attention