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Quality Characterization of Electroless Copper Deposition on Polymer after Laser-Induced Selective Activation Using Color-Distance Metrics

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17th International Symposium on Laser Precision Microfabrication, Wyndham Grand Xi'an South, Xi'an, China, May 23 - 27, 2016 **Day 1 Monday May 23 14:50 – 15:10 Mo1-O-6**

3D molded interconnecting device



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Selective metallization on polymer



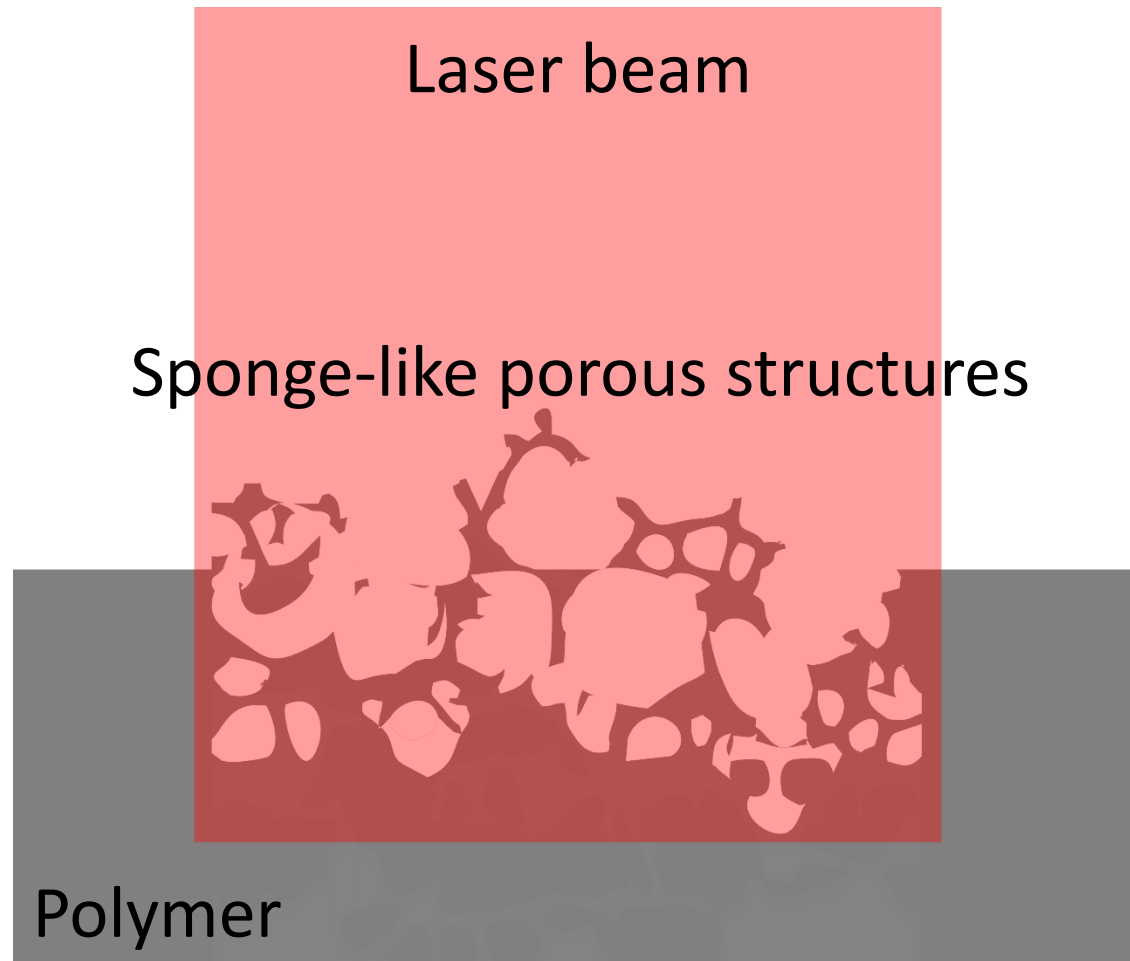
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- LPKF-LDS®
- MIPTECH-PANASONIC®
- Laser-induced selective activation (LISA) and electroless copper plating (ECP)

Laser-induced selective activation (LISA)



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LISA
1 step process

Electroless copper plating (ECP) on polymer after LISA



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ECP

3 step process

1. Activation with palladium
2. Cleaning in distilled water
3. Electroless copper plating

Quality characterization of copper deposition



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Sheet resistance

$$R_s = \frac{1}{h\sigma}$$

In this work, the new colorimetric method of quality characterization of ECP on polymer after LISA using **color-distance** metrics is proposed.

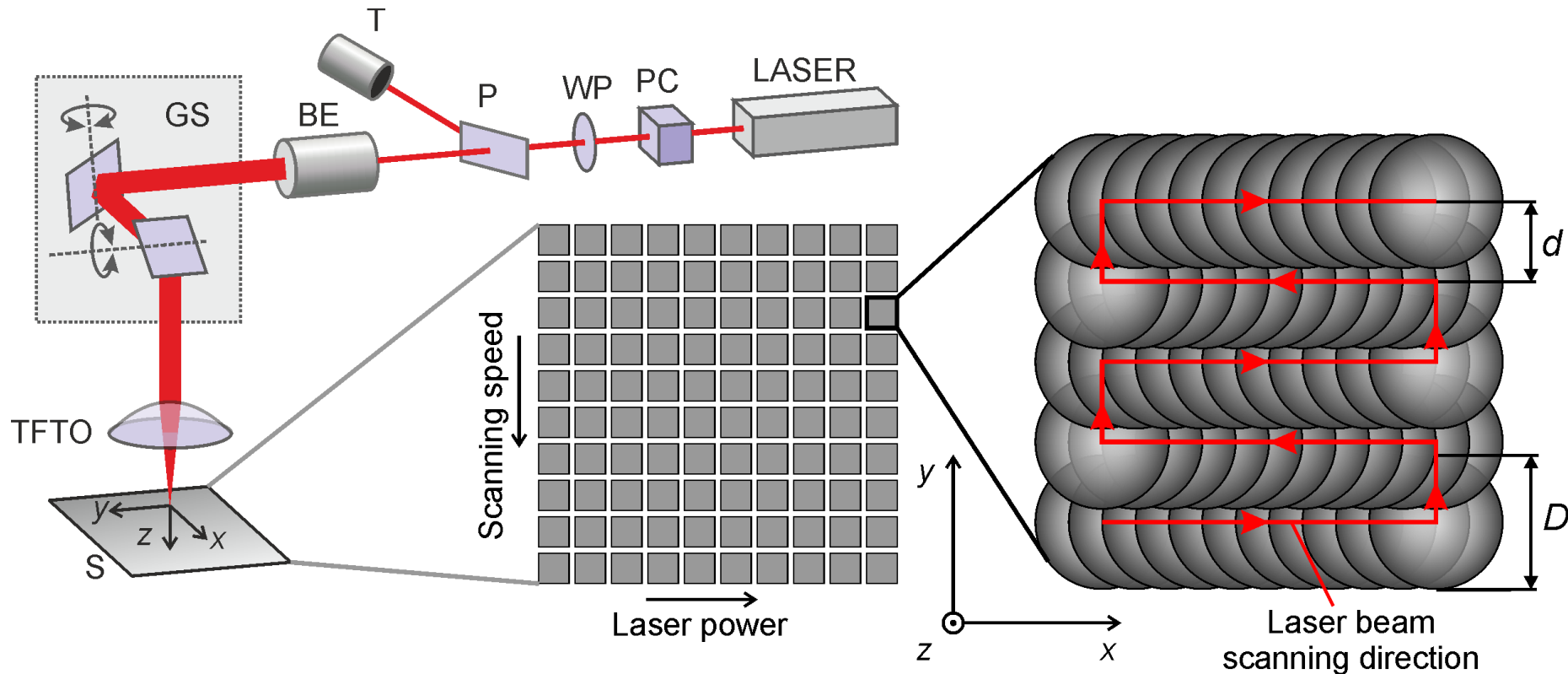
Copper deposition

Thickness h

σ Conductivity



Experimental setup and procedure for LISA



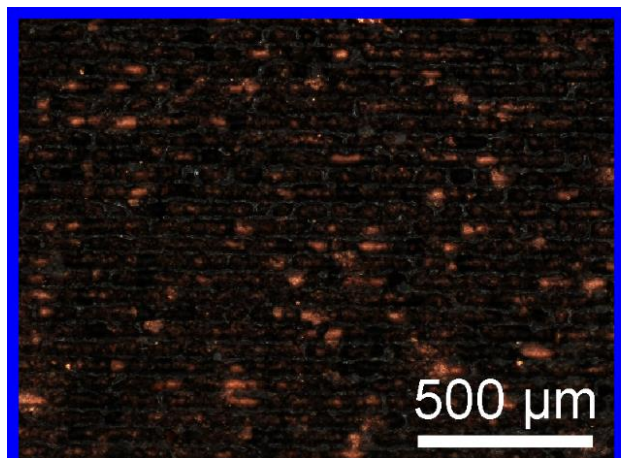
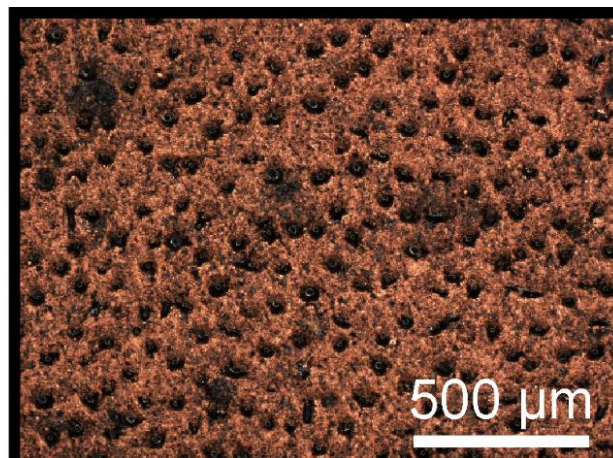
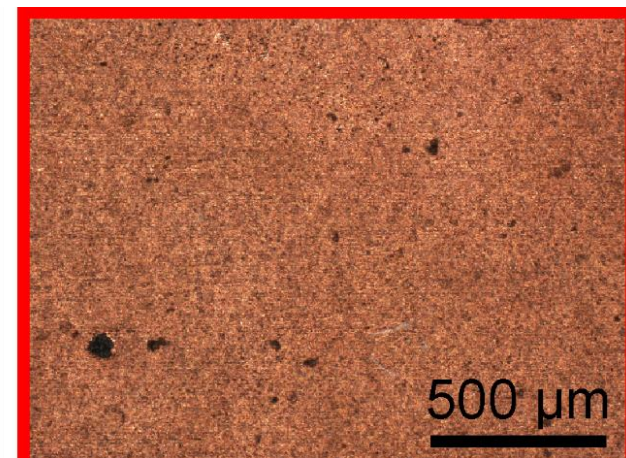
Laser (Baltic HP, Ekspla):
pulse duration 10 ns;
pulse repetition rate 50 kHz;
wavelength of irradiation 532 nm;
mean laser power up to 1.0 W.

Polycarbonate/acrylonitrile
butadiene styrene (PC/ABS)
polymer

Copper deposition on polymer



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Poor plating
 $R_s = 4300 \Omega/\text{sq}$

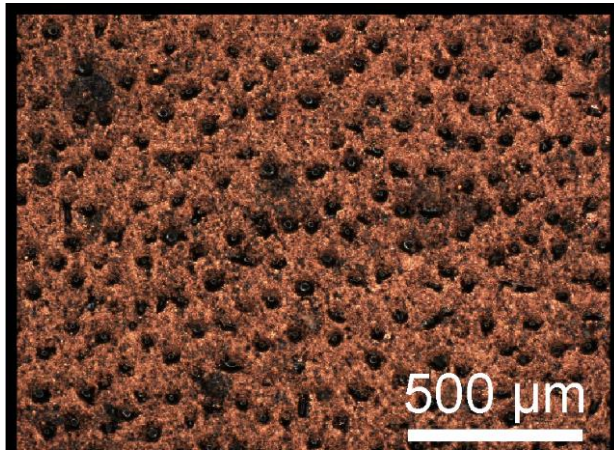
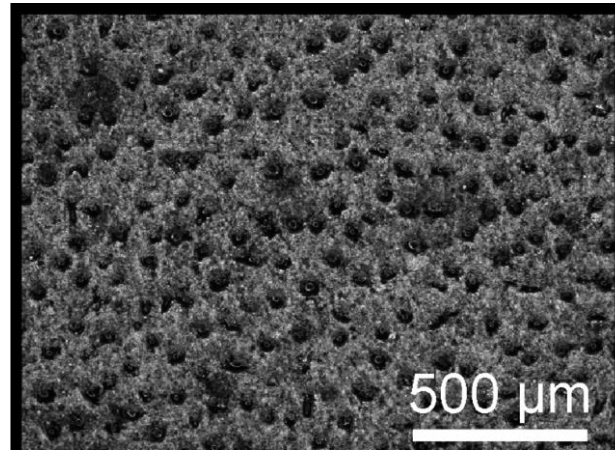
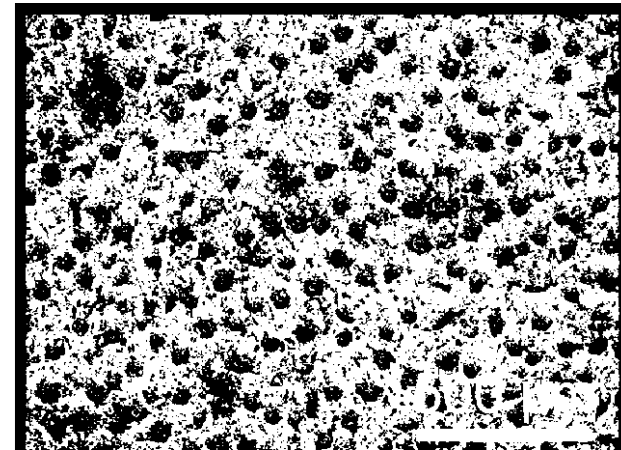
Moderate plating
 $R_s = 3.1 \Omega/\text{sq}$

Good plating
 $R_s = 0.14 \Omega/\text{sq}$

Area fraction of copper

Conversion to grayscale, luminance:

$$Y' = 0.299R_{\text{ECP}} + 0.587G_{\text{ECP}} + 0.114B_{\text{ECP}}$$



Area fraction of copper:

$$\phi_{\text{frac}} = \frac{W}{B+W}$$

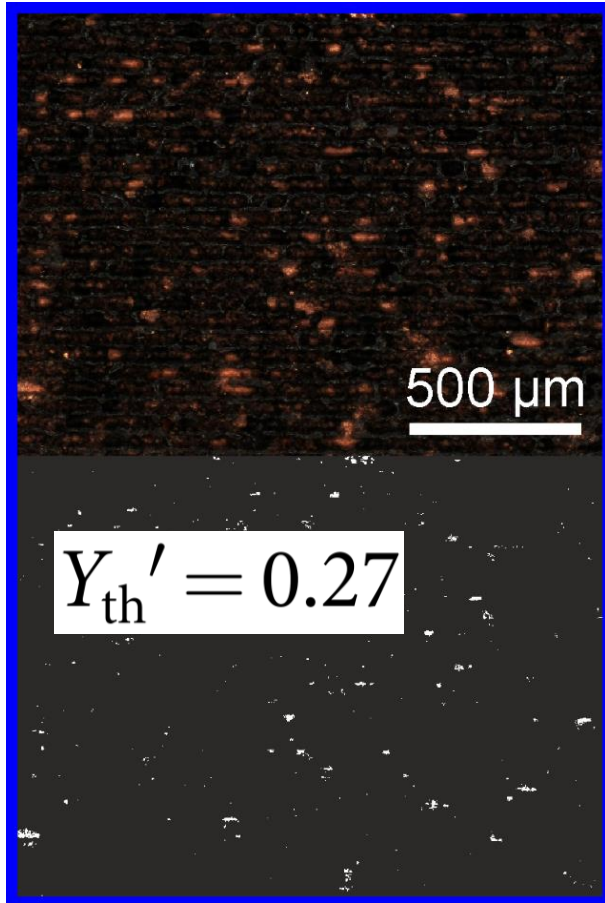
Conversion to black and white,
threshold:

$$Y'_{\text{th}}$$

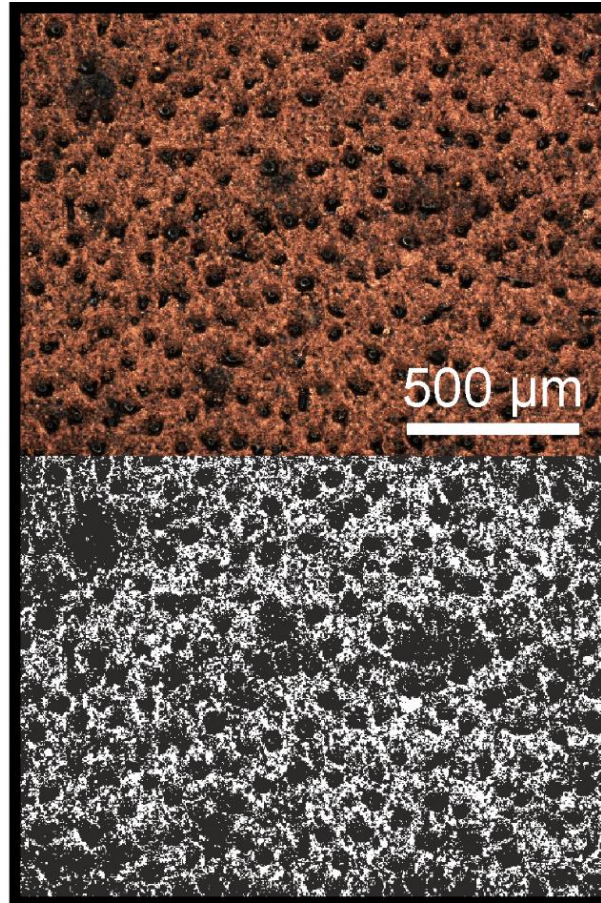
Area fraction of copper



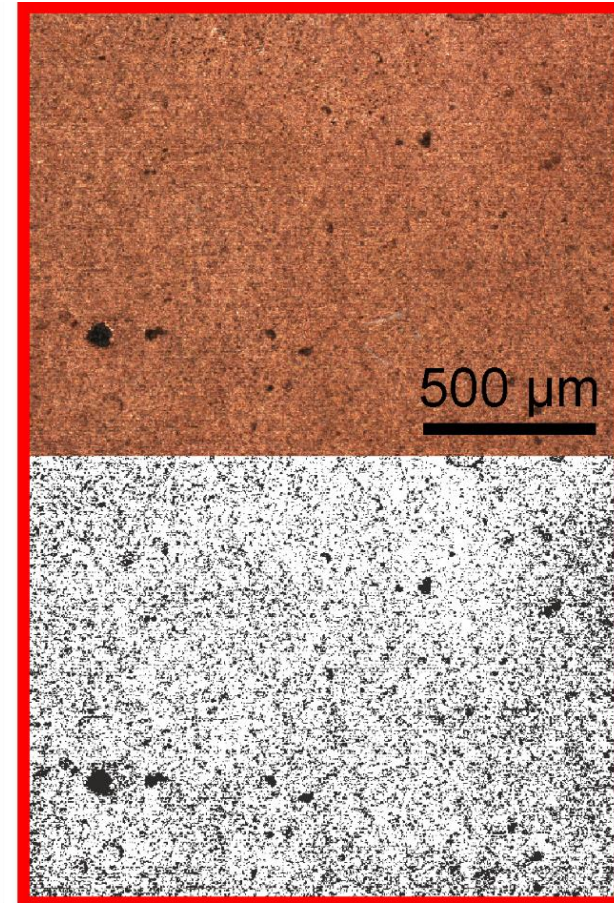
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Poor plating
 $R_s = 4300 \, \Omega/\text{sq}$
 $\phi_{\text{frac}} \approx 0.03$



Moderate plating
 $R_s = 3.1 \, \Omega/\text{sq}$
 $\phi_{\text{frac}} \approx 0.65$



Good plating
 $R_s = 0.14 \, \Omega/\text{sq}$
 $\phi_{\text{frac}} \approx 0.90$

Colour difference

Colour difference:

$$\Delta E = \sqrt{(R_{\text{ECP}} - R_{\text{LISA}})^2 + (G_{\text{ECP}} - G_{\text{LISA}})^2 + (B_{\text{ECP}} - B_{\text{LISA}})^2}$$

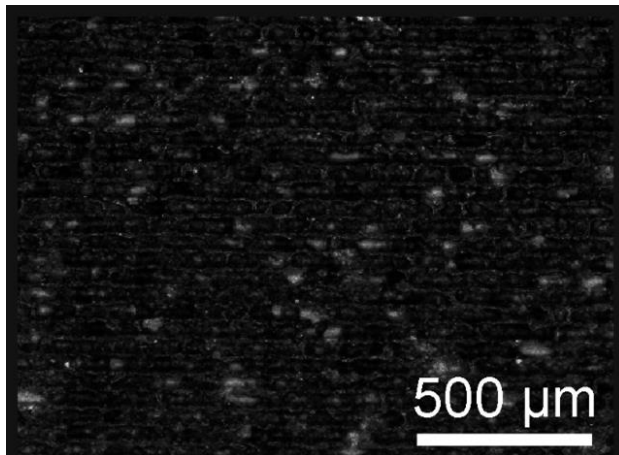


Image after LISA

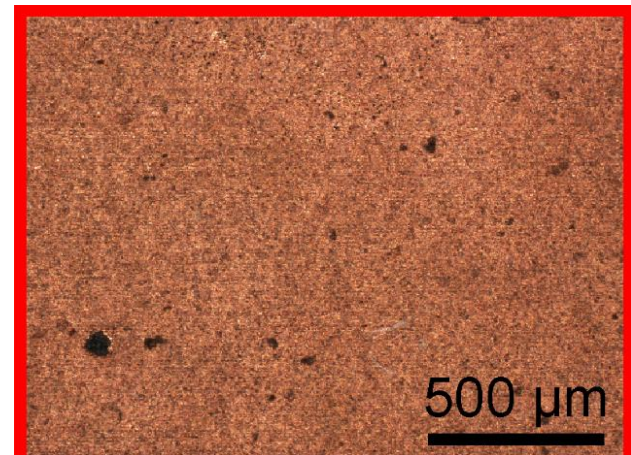


Image after ECP

Colour difference



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ϕ_{frac} **vs** ΔE

500 μm

500 μm

500 μm

Poor plating

$$R_s = 4300 \, \Omega/\text{sq}$$

$$\phi_{\text{frac}} \approx 0.03$$

$$\Delta E = 0.06$$

Moderate plating

$$R_s = 3.1 \, \Omega/\text{sq}$$

$$\phi_{\text{frac}} \approx 0.65$$

$$\Delta E = 0.44$$

Good plating

$$R_s = 0.14 \, \Omega/\text{sq}$$

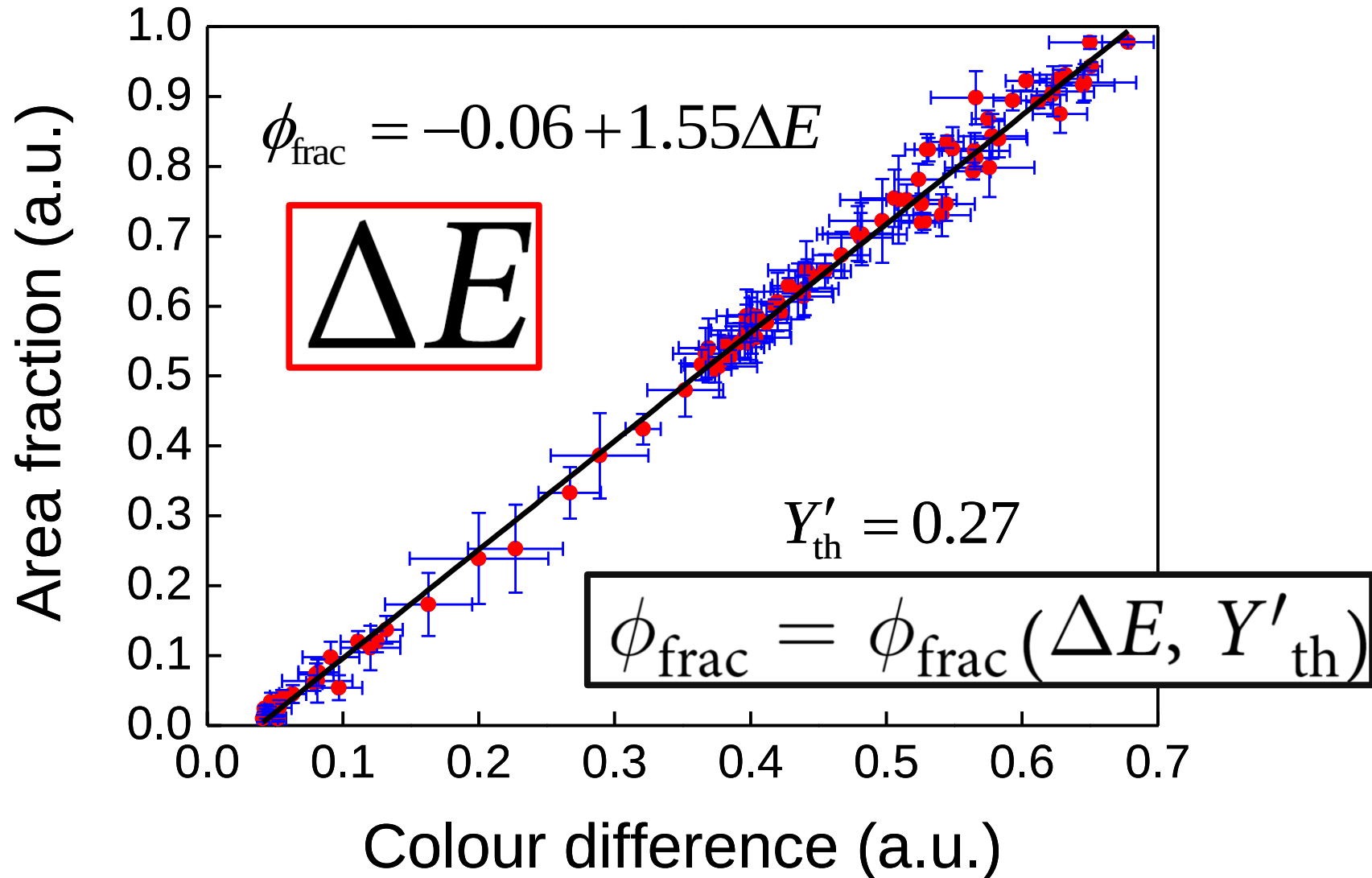
$$\phi_{\text{frac}} \approx 0.90$$

$$\Delta E = 0.62$$

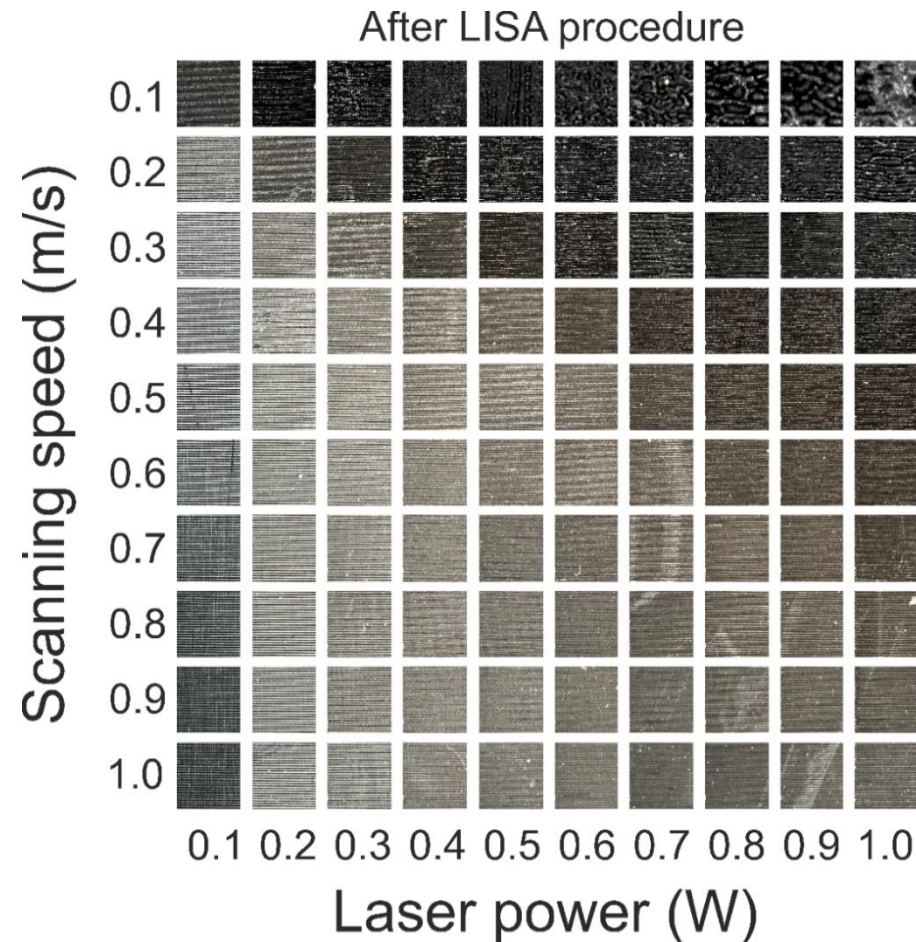
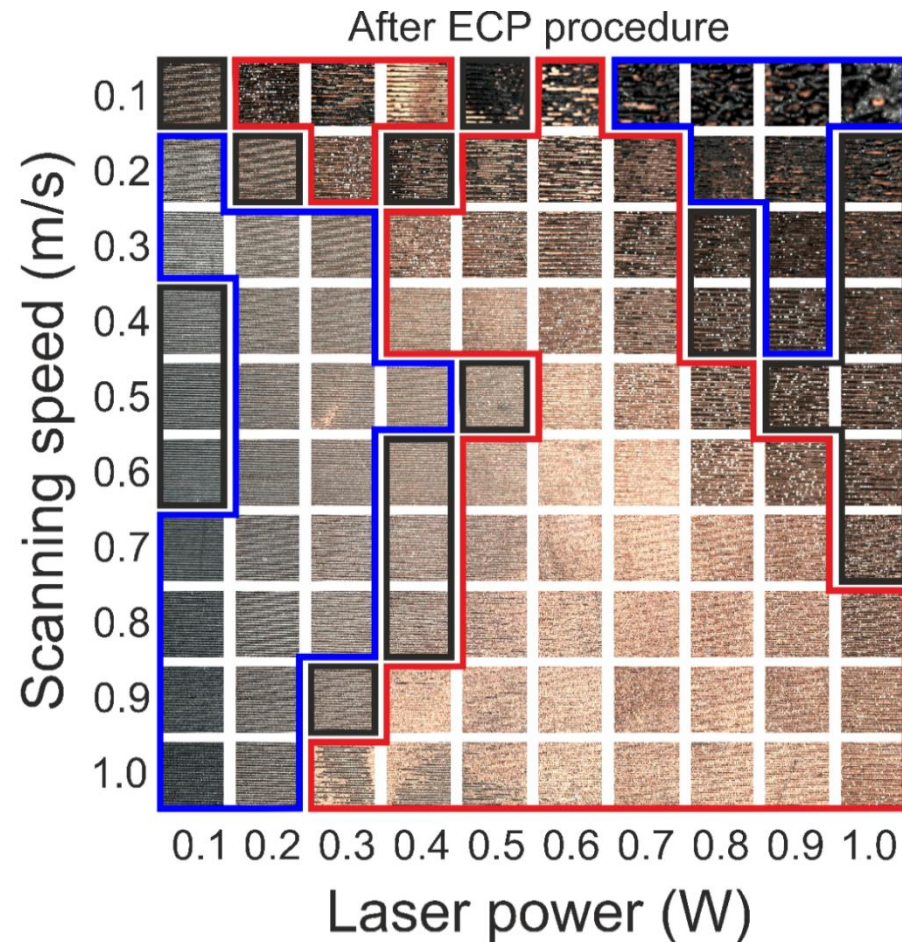
Area fraction vs colour difference



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Images of the polymer before and after copper plating



Poor plating

$$10 \, \Omega/\text{sq} < R_s < 2 \times 10^4 \, \Omega/\text{sq}$$

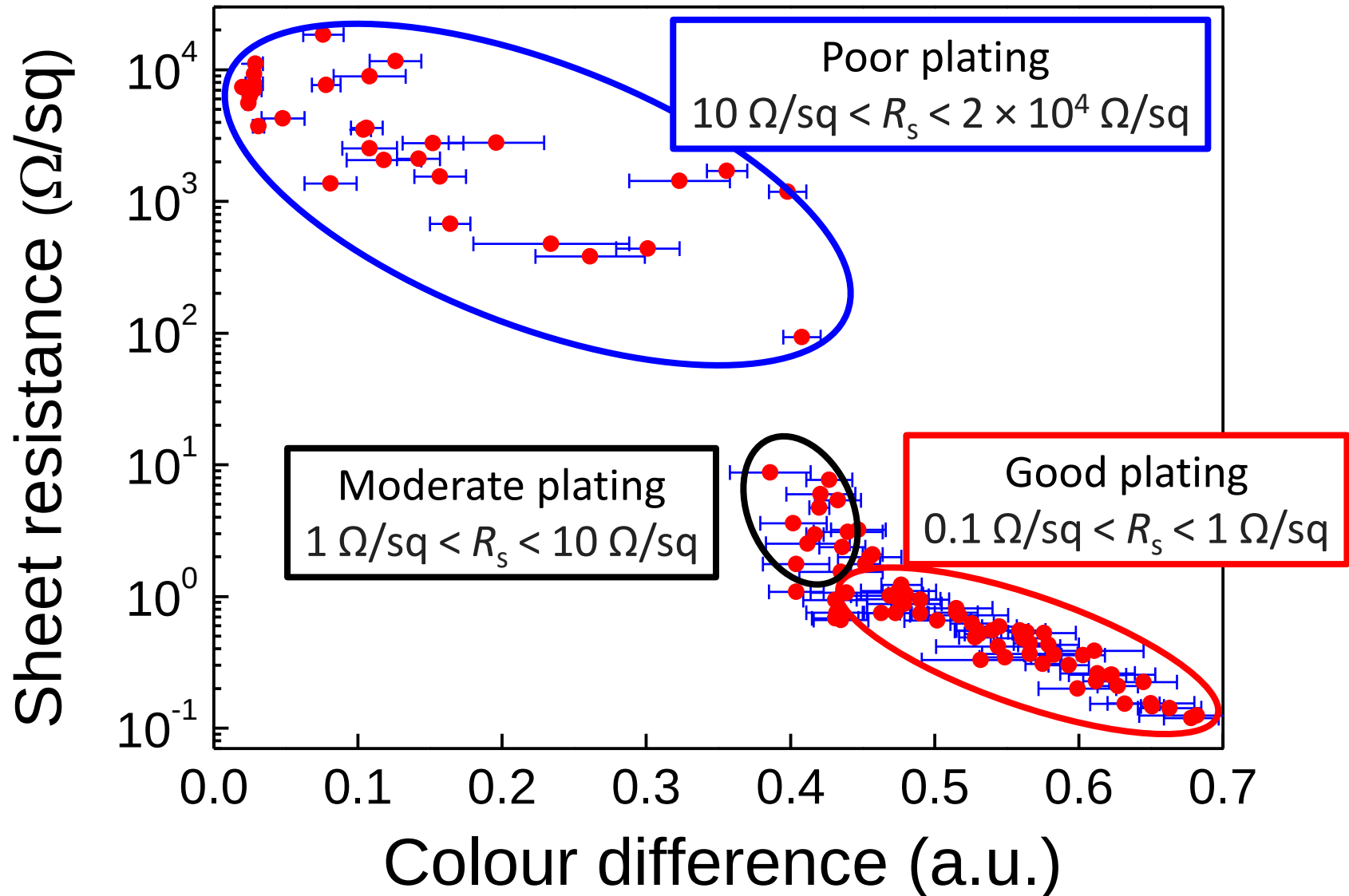
Moderate plating

$$1 \, \Omega/\text{sq} < R_s < 10 \, \Omega/\text{sq}$$

Good plating

$$0.1 \, \Omega/\text{sq} < R_s < 1 \, \Omega/\text{sq}$$

Sheet resistance vs colour difference



Percolation model of polymer and metal mixture



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Conductivity:

$$\sigma(\phi_{\text{frac}}) = \begin{cases} \sigma_m(\phi_{\text{frac}} - \phi_{\text{crit}})^t & \text{if } \phi_{\text{frac}} > \phi_{\text{crit}} \\ \sigma_m \left(\frac{\sigma_m}{\sigma_p} \right)^s & \text{if } \phi_{\text{frac}} = \phi_{\text{crit}} \\ \sigma_p(\phi_{\text{crit}} - \phi_{\text{frac}})^{-q}, \quad q > 0 & \text{if } \phi_{\text{frac}} < \phi_{\text{crit}} \end{cases}$$

Poor plating

$$R_s = 4300 \, \Omega/\text{sq}$$

$$\phi_{\text{frac}} \approx 0.03$$

$$\Delta E = 0.06$$

500 μm

Moderate plating

$$R_s = 3.1 \, \Omega/\text{sq}$$

$$\phi_{\text{frac}} \approx 0.65$$

$$\Delta E = 0.44$$

500 μm

Good plating

$$R_s = 0.14 \, \Omega/\text{sq}$$

$$\phi_{\text{frac}} \approx 0.90$$

$$\Delta E = 0.62$$

500 μm

Percolation model of sheet resistance



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Sheet resistance:

$$R_s = R_s(\phi_{\text{frac}}) = \frac{1}{h\sigma(\phi_{\text{frac}})}$$

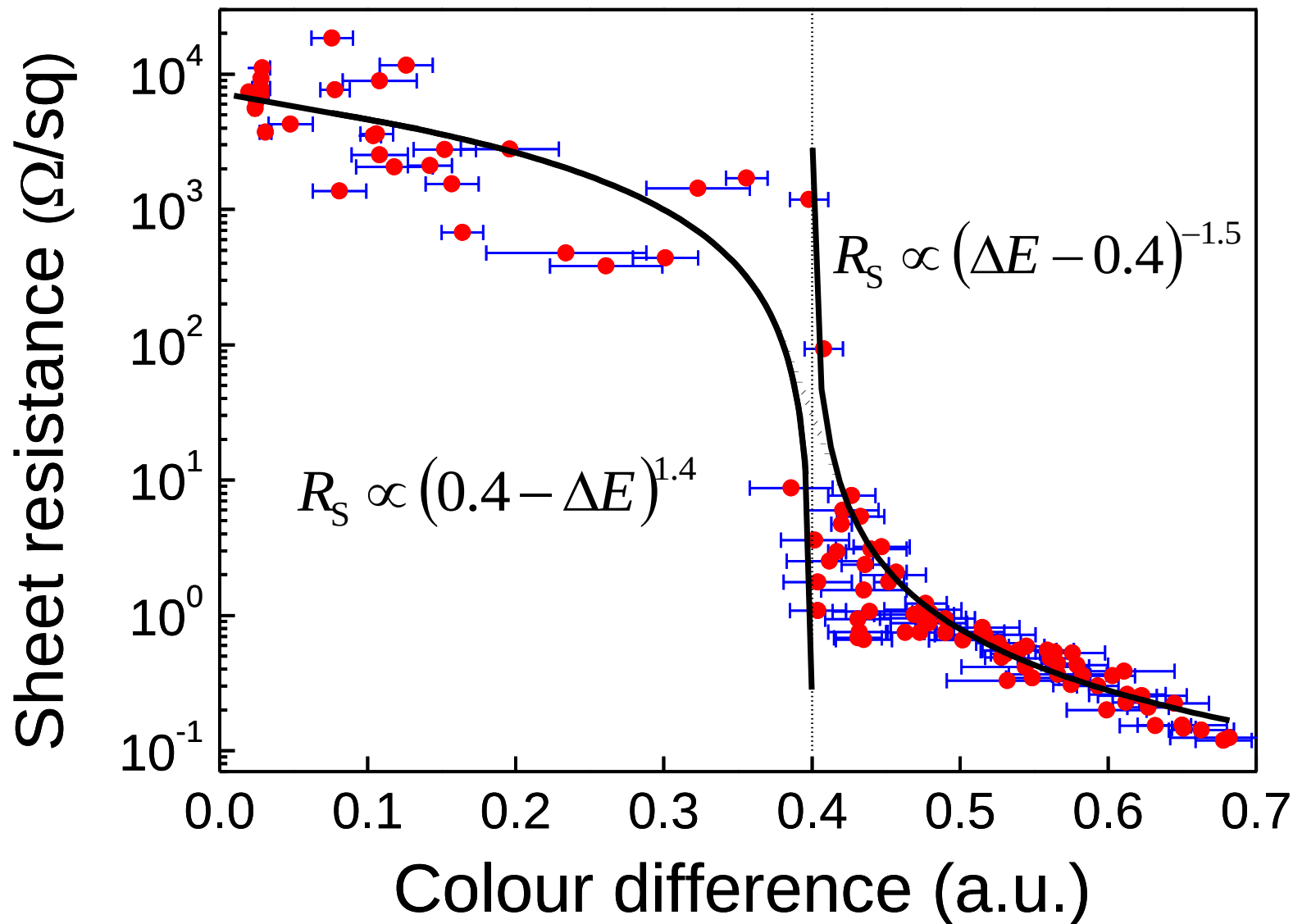
Area fraction is proportional to colour distance:

$$\phi_{\text{frac}} \propto \Delta E$$

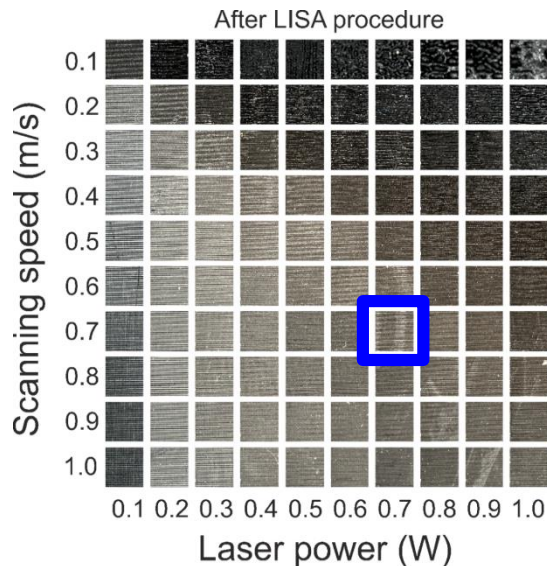
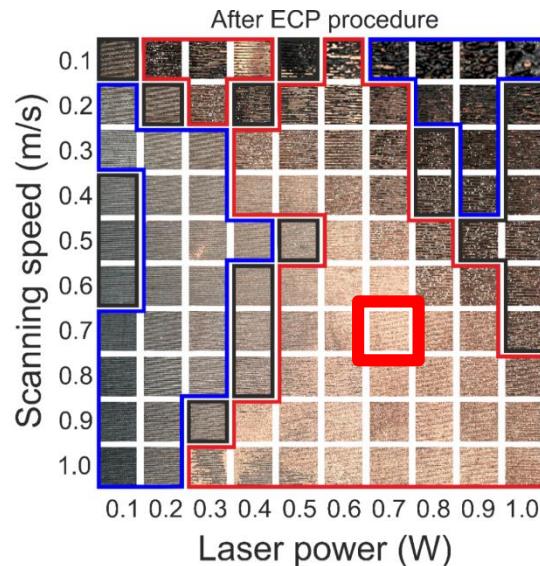
By combining all equations:

$$R_s = R_s(\Delta E)$$

Percolation model of sheet resistance

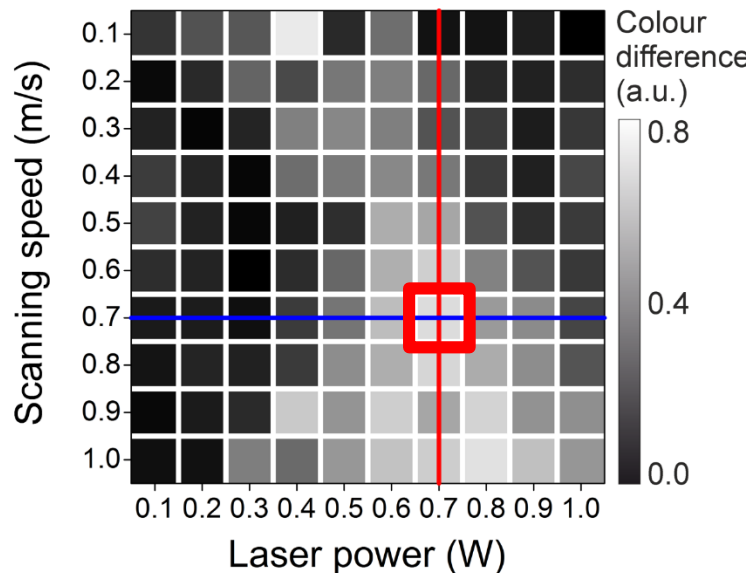
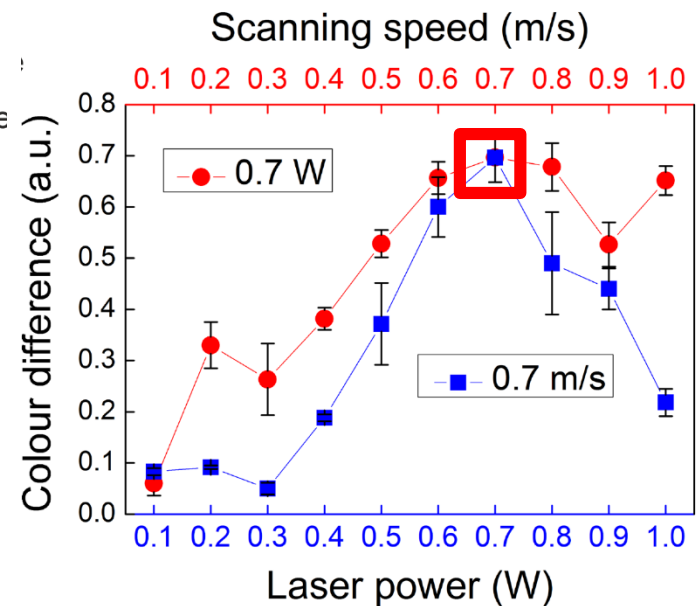


Colour difference vs processing parameters



Best plating quality:
 $R_s = 0.1 \Omega/\text{sq.}$

Optimal
processing
parameters:
 $P = 0.7 \text{ W};$
 $v = 0.7 \text{ m/s.}$

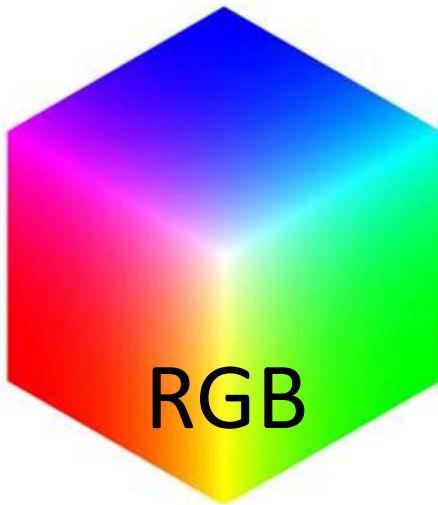
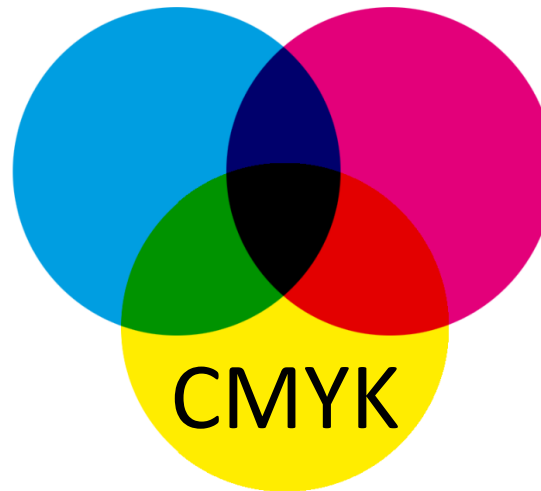
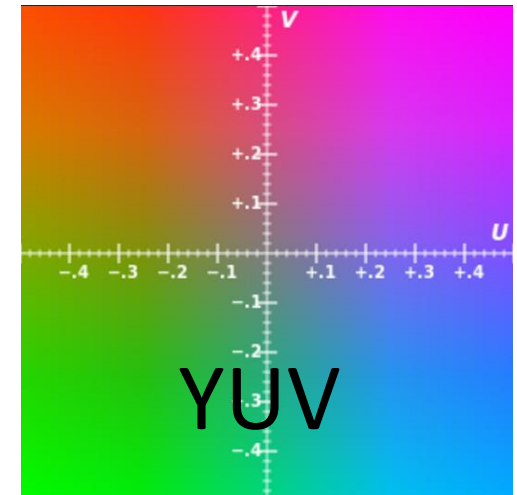
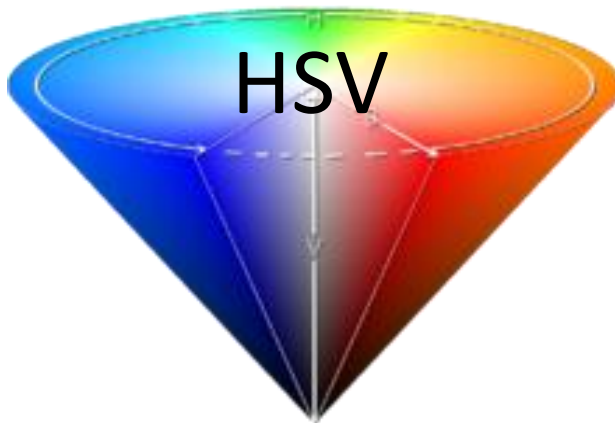
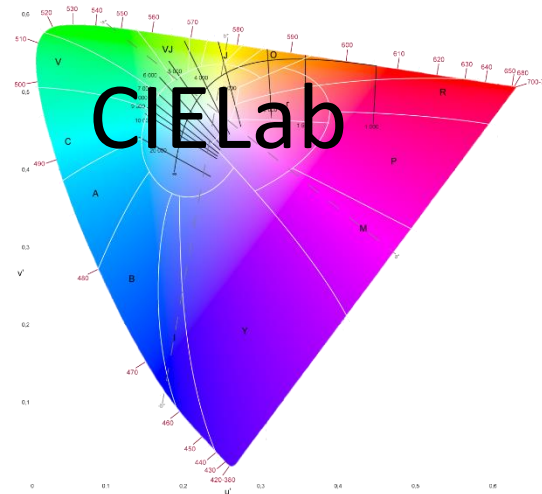


Colour space



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Five major models of colour spaces:



Conclusions

- The sheet resistance of copper layers decay by the power-law with increasing of the colour difference.
- The percolation theory of electrical conductance of insulator-conductor mixture has been adopted in order to explain the experimental results. Three distinguishable regions of sheet resistance decay correspond well with the generalized percolation model.
- The new proposed method has been proven to be independent on the colour space used for the colour difference measurements.
- A new colorimetric method is an easy tool for evaluation of the metal plating quality requiring only an optical microscope or a colorimeter.



Thank you for the attention!

The research leading to these results was funded by the European Union 7FP Programme under grant agreement No. 609355 (APPOLO).

M. Gedvilas *et al.*, *Scientific Reports* **6**, 22963 (2016).

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