Supplemental Information for "DLC-Engineered Flat Gravure Surface: Enabling Sustainable Fabrication to Replace chrome for Printing Conductive Line Electrodes in Flexible Electronics"

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Trial. No.	Experiment Name	Print Conditions			Reference Figure
		Blade Type	Ink Type	Substrate Type	
T1	Trial One Print Experiment	Metal	Black60	White PET	Figure S-17 and S-18
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T3	Trial Three Print Experiment	Metal	ECI7007	White PET	Figure S-21 and S-22
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3D parameter filter tools:	**Parameter symbol and its parameter name given in parenthesis:**	**Description:**
S Parameters– Height	S_a (average roughness in nm) S_q (average root mean square roughness in nm) S_z (maximum height of the surface in nm).	The S_a and S_q parameters represent an overall measure of the texture comprising the surface, while S_z represents the the maximum height of the surface.
S Parameter– Hybrid tool	S_{dq} (average root mean square slope in degree) S_{dr} (developed interfacial area ratio)	S_{dq} is the root mean square (RMS) surface slope comprising the surface, evaluated over all directions. S_{dr} is the developed interfacial area ratio expressed as the percentage of the additional surface area contributed by the texture compared to an ideal plane that is the size of the measurement region
Rz Analysis (Legacy parameter & not a 3D parameter)	Rz (average roughness)	Used for capturing the average of the 10 highest to 10 lowest points perpendicular to the surface

Table S-1*. Names of 3D parameter filter tools used as Analyzer algorithm in Vision 64 software to evaluate the OPDx file that has 3D surface data of the plain portion of chrome and standard DLC layers*

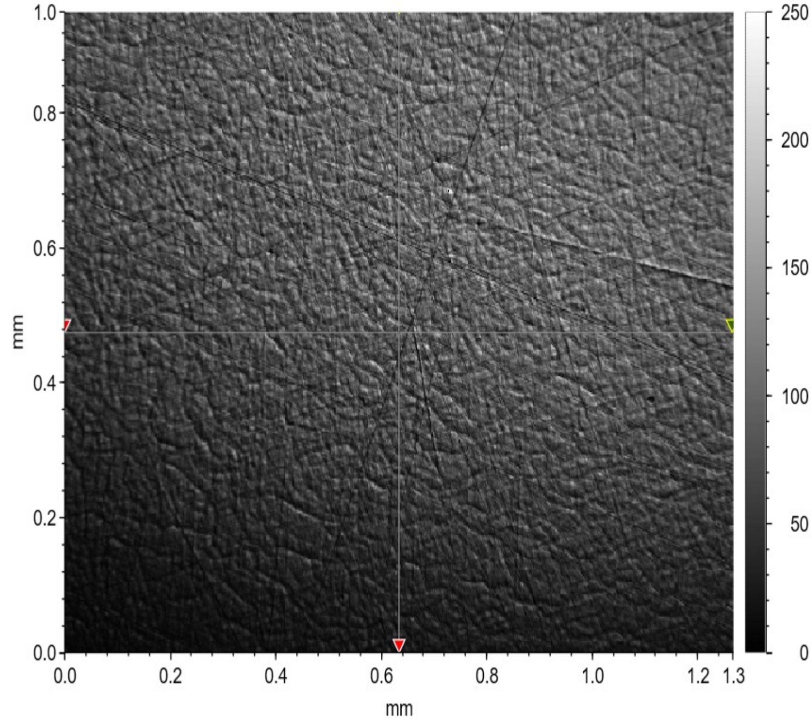
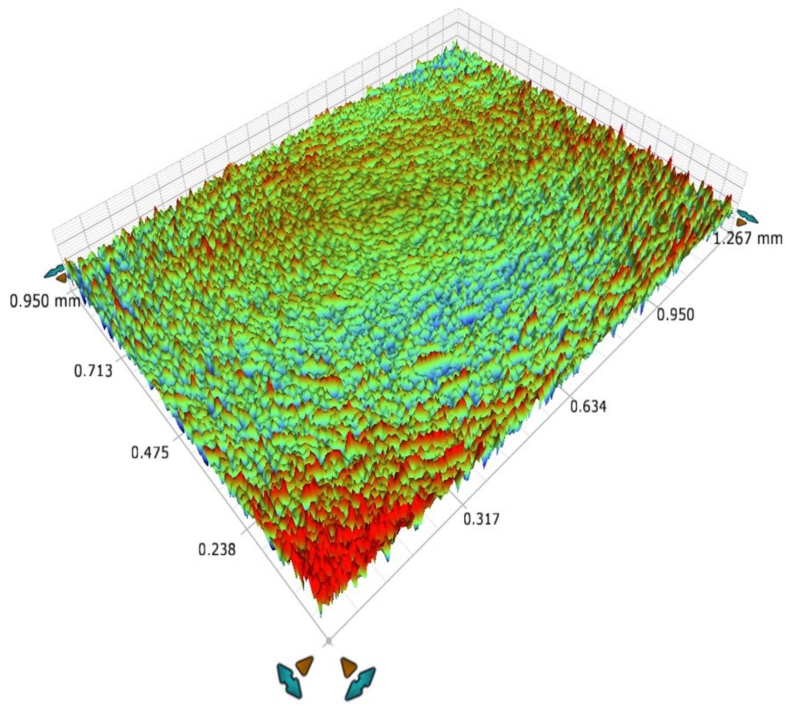
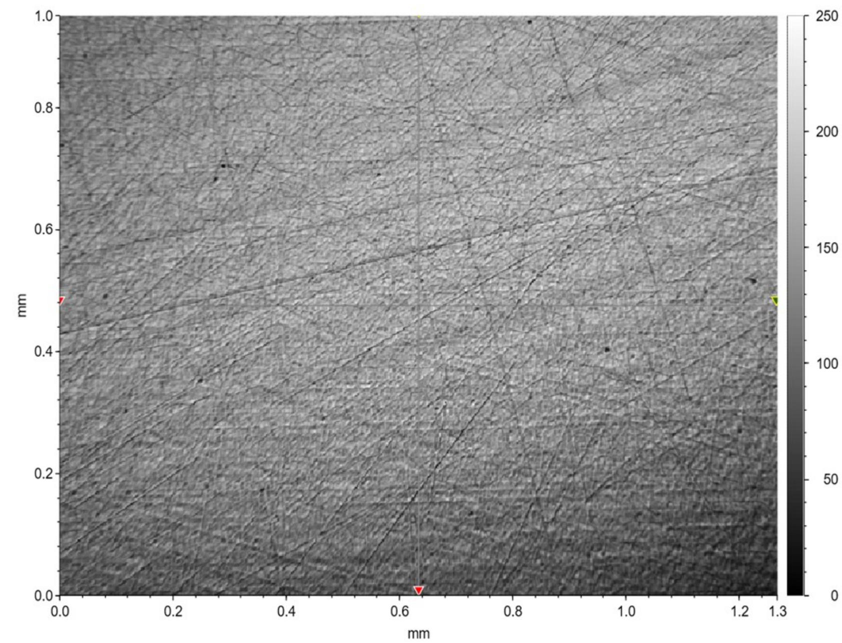
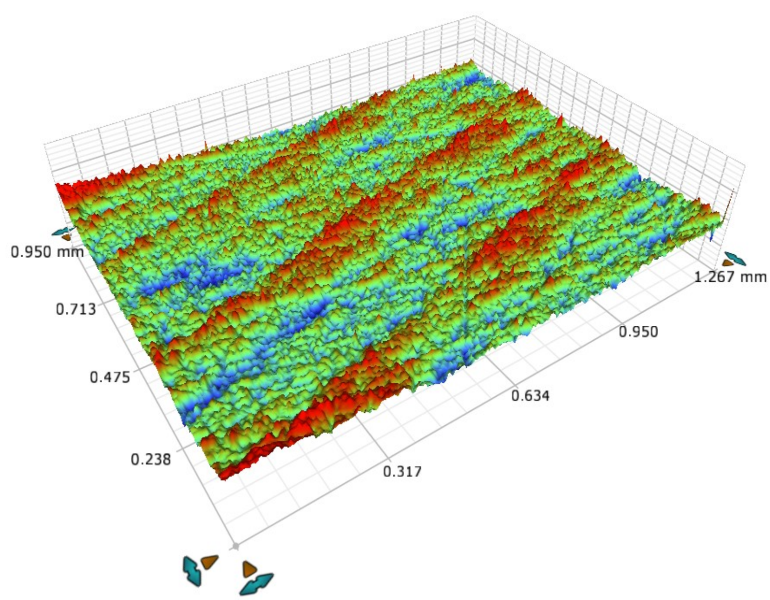
Bruker Images of Chrome Surface

Gray Scale Image

3D Contour Color Plot

Figure S-1*. Bruker Images of chrome Surface. (A) Gray Scale Image and (B) 3D Contour Color Plot.*

Bruker Images of Standard DLC Surface



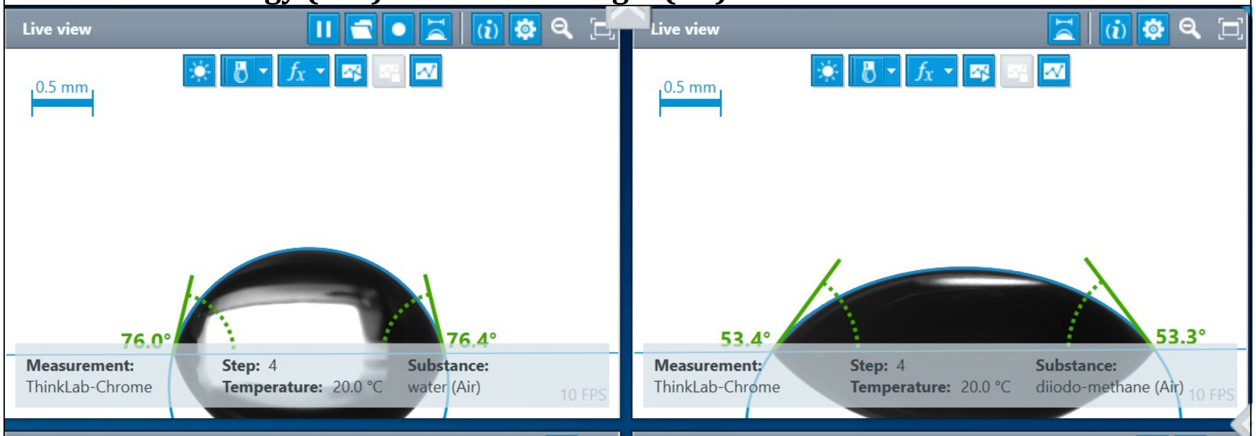
(A) Gray Scale Image



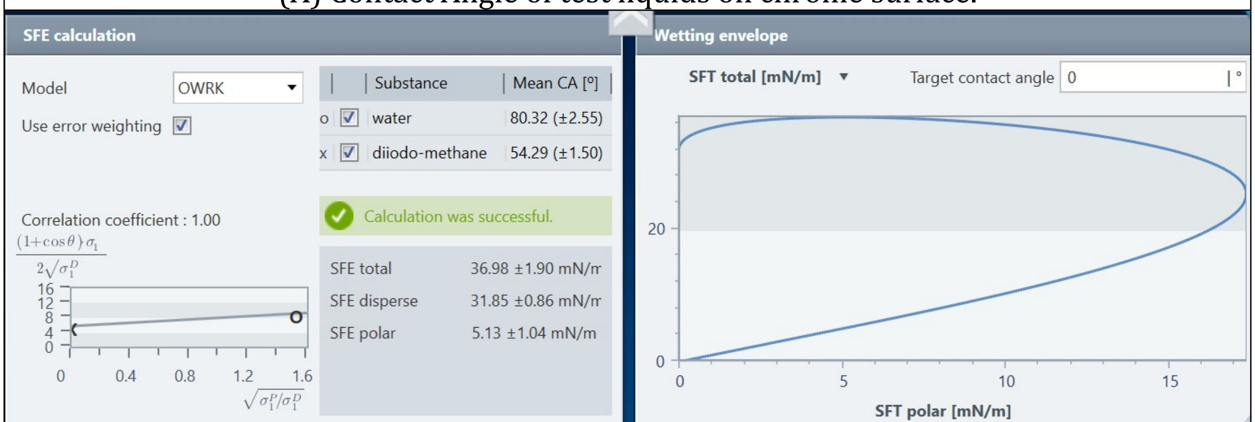
(B) 3D Contour Color Plot

Figure S-2. *Bruker Images of standard DLC Surface. (A) Gray Scale Image and (B) 3D Contour Color Plot.*

Surface Free Energy (SFE) and Contact Angle (CA) on chrome Surface:



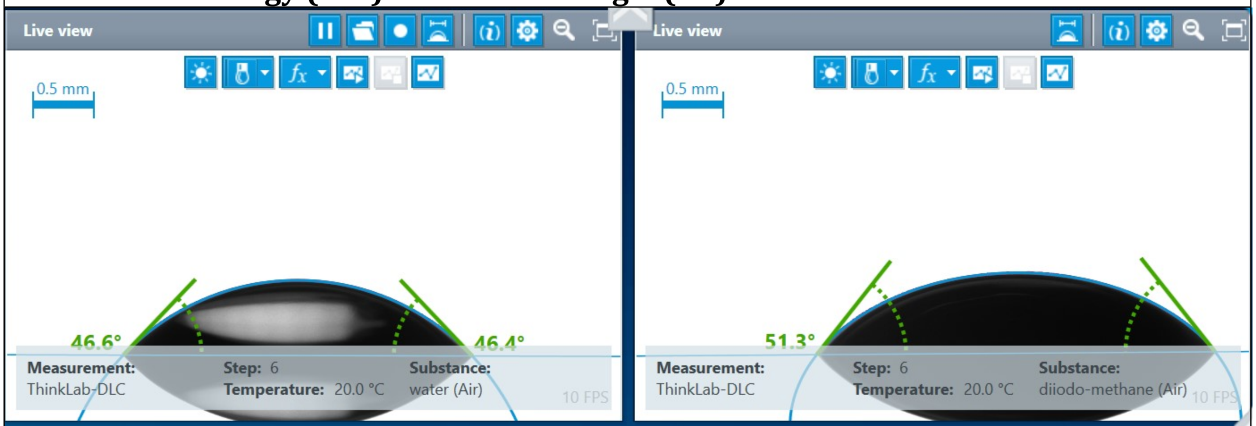
(A) Contact Angle of test liquids on chrome surface.



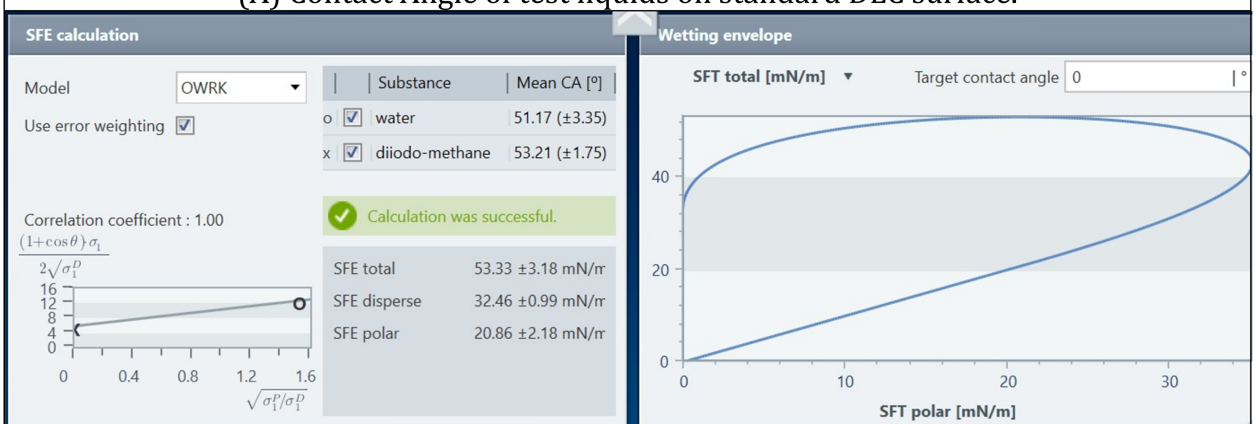
(B) Surface Free Energy of chrome surface and its wetting envelop.

***Figure S-3**. Contact Angle and Surface Free Energy measured on chrome Surface using the KRÜSS MSA (Mobile Surface Analyzer). (A)Contact Angle of test liquids, water and diiodo-methane on chrome surface. (B) Surface Free Energy calculation (SFE total, SFE disperse and SFE polar) using Owens, Wendt, Rabel and Kaelble (OWRK) method along with wetting envelop plot.*

Surface Free Energy (SFE) and Contact Angle (CA) on standard DLC Surface:



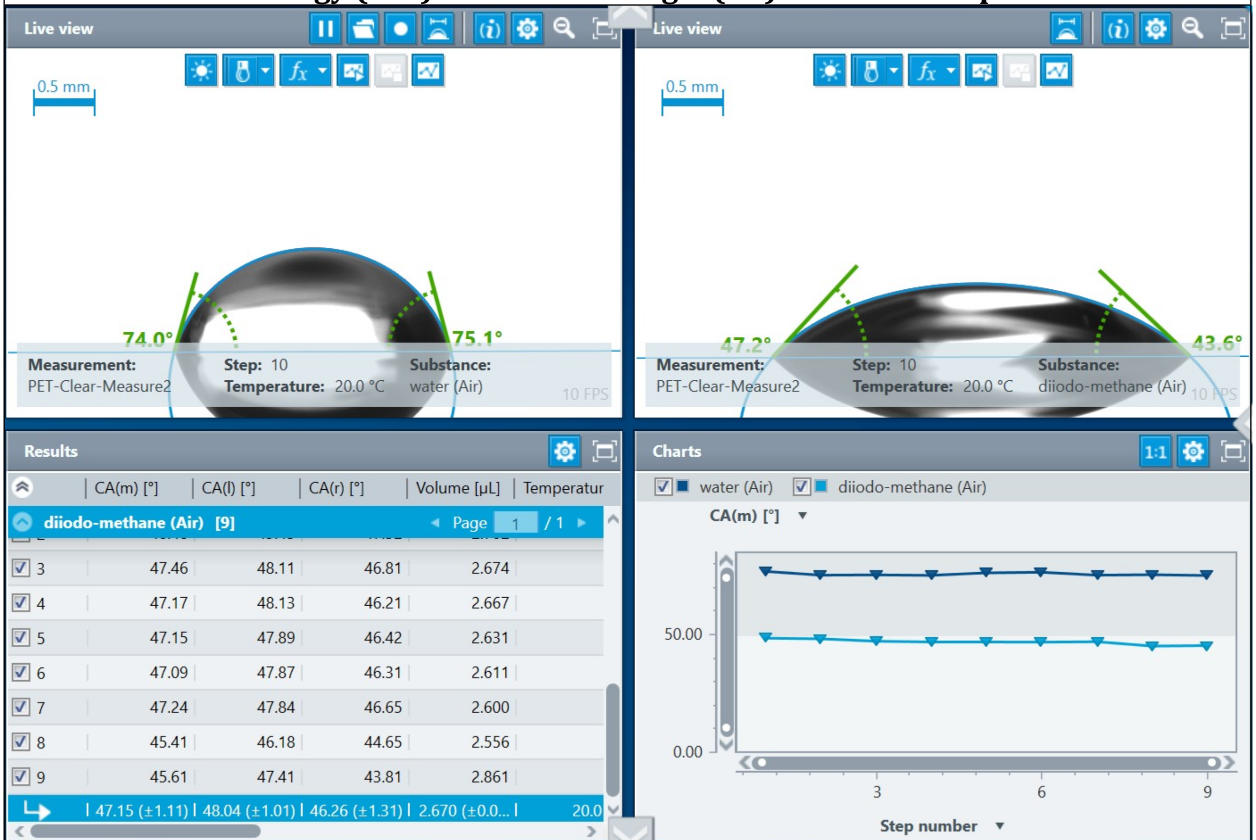
(A) Contact Angle of test liquids on standard DLC surface.



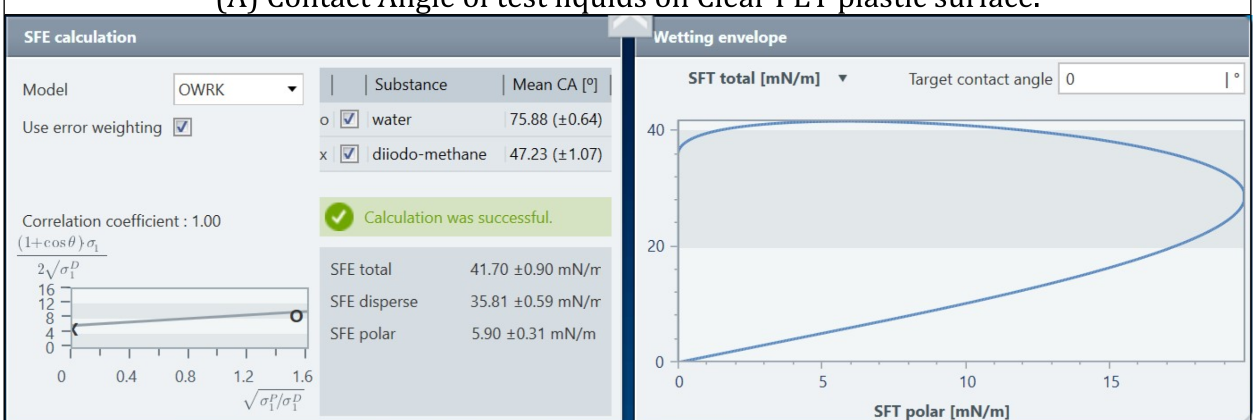
(B) Surface Free Energy of standard DLC surface and its wetting envelop.

***Figure S-4**. Contact Angle and Surface Free Energy measured on standard DLC surface using the KRÜSS MSA (Mobile Surface Analyzer). (A)Contact Angle of test liquids, water and diiodo-methane on standard DLC surface. (B) Surface Free Energy calculation (SFE total, SFE disperse and SFE polar) using Owens, Wendt, Rabel and Kaelble (OWRK) method along with wetting envelop plot.*

Surface Free Energy (SFE) and Contact Angle (CA) on Clear PET plastic surface:



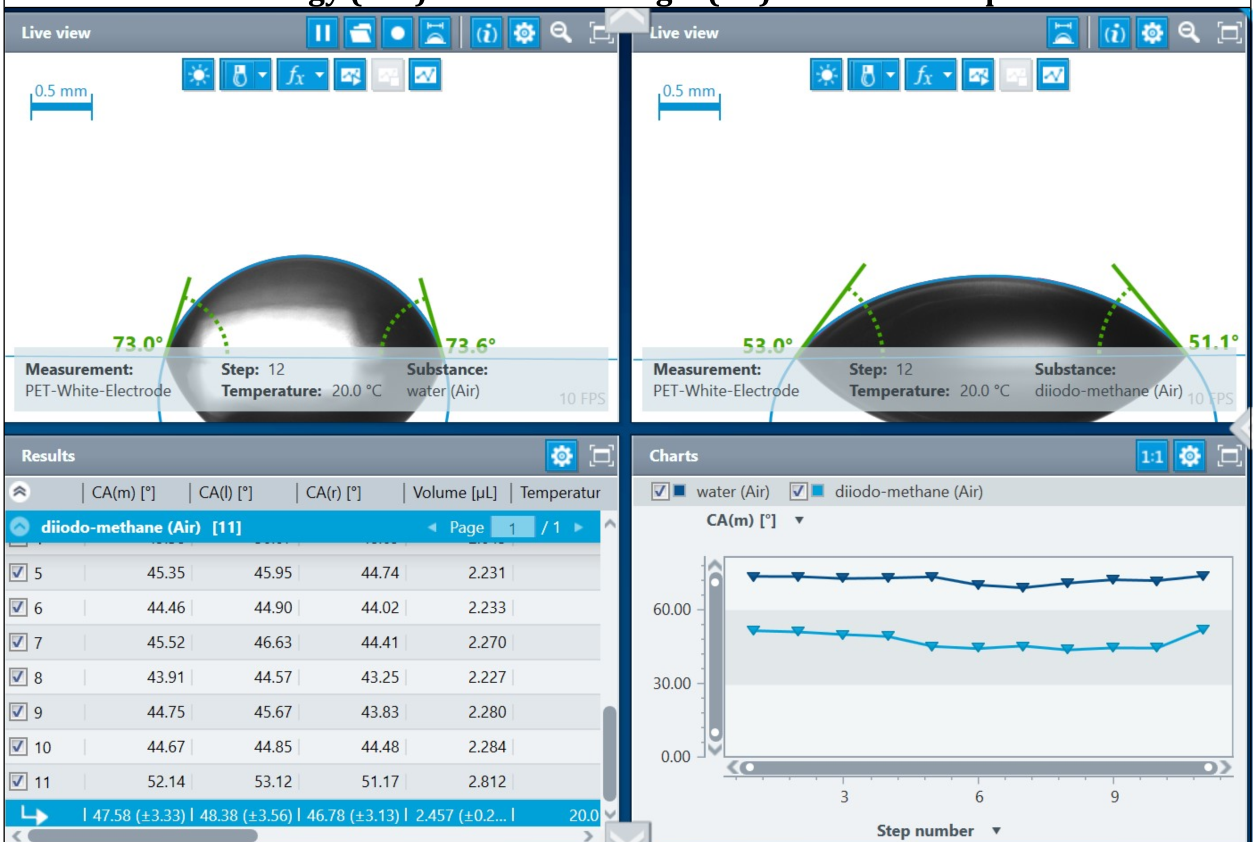
(A) Contact Angle of test liquids on Clear PET plastic surface.



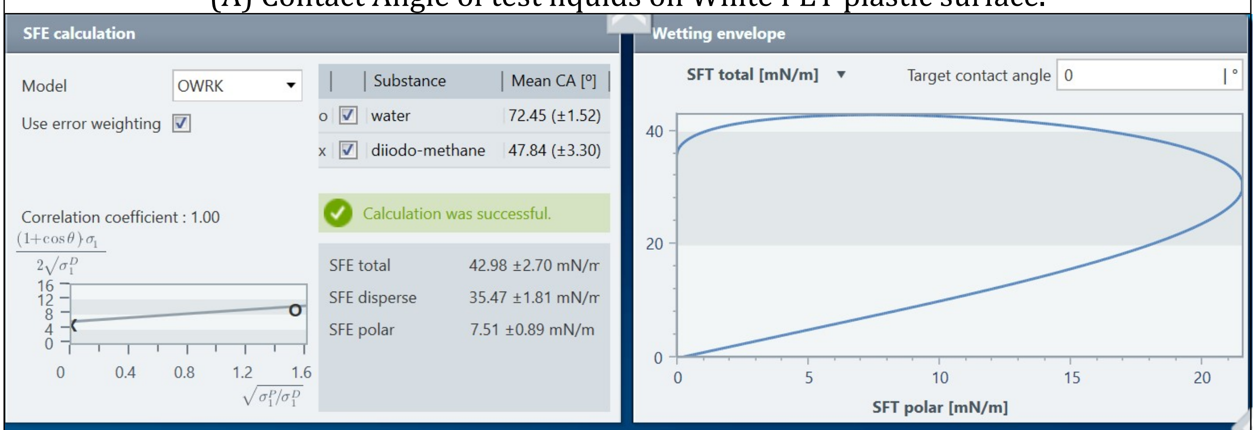
(B) Surface Free Energy of Clear PET plastic surface and its wetting envelop.

Figure S-5*. Contact Angle and Surface Free Energy measured on Clear PET plastic surface using the KRÜSS MSA (Mobile Surface Analyzer). (A)Contact Angle of test liquids, water and diiodo-methane on Clear PET plastic surface. (B) Surface Free Energy calculation (SFE total, SFE disperse and SFE polar) using Owens, Wendt, Rabel and Kaelble (OWRK) method along with wetting envelop plot.*

Surface Free Energy (SFE) and Contact Angle (CA) on White PET plastic surface:



(A) Contact Angle of test liquids on White PET plastic surface.



(B) Surface Free Energy of White PET plastic surface and its wetting envelop.

Figure S-6*. Contact Angle and Surface Free Energy measured on White PET plastic surface using the KRÜSS MSA (Mobile Surface Analyzer). (A)Contact Angle of test liquids, water and diiodo-methane on White PET plastic surface. (B) Surface Free Energy calculation (SFE total, SFE disperse and SFE polar) using Owens, Wendt, Rabel and Kaelble (OWRK) method along with wetting envelop plot.*

Surface Tension (ST) of ECI 7007 Ink:

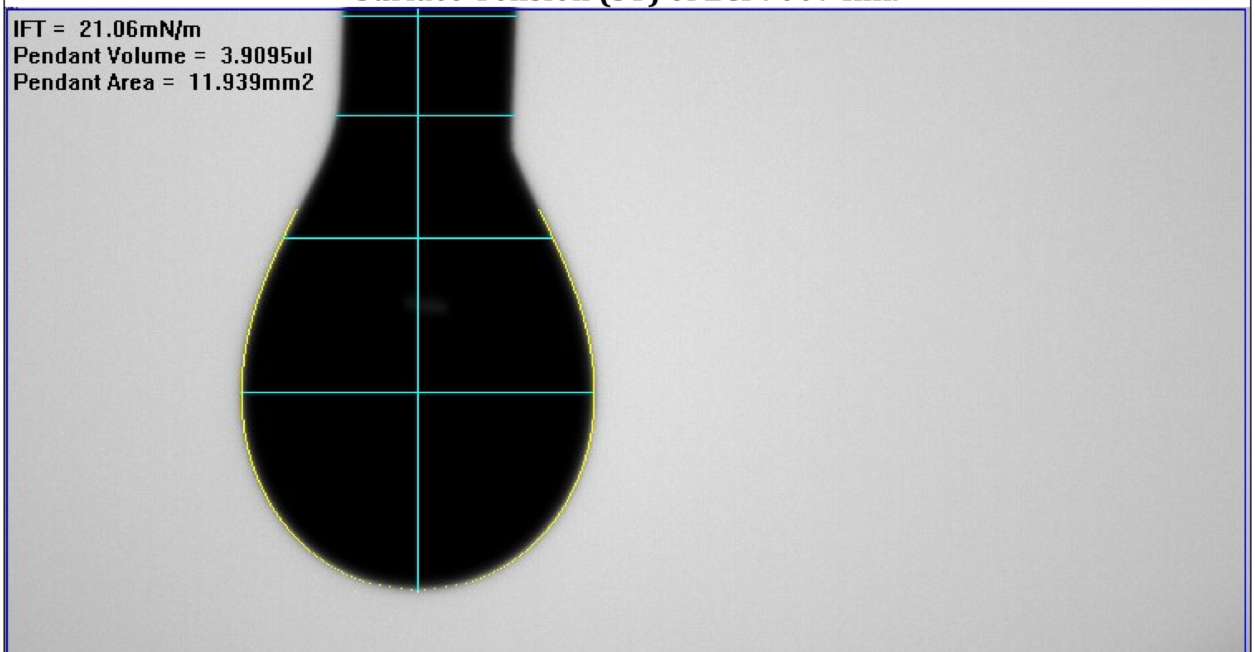


Figure S-7. *Surface Tension (ST) of ECI 7007 ink measured with the instrument First Ten Angstroms FTA200 using Pendant Drop Method.*

Surface Tension (ST) of Black 60 ink:

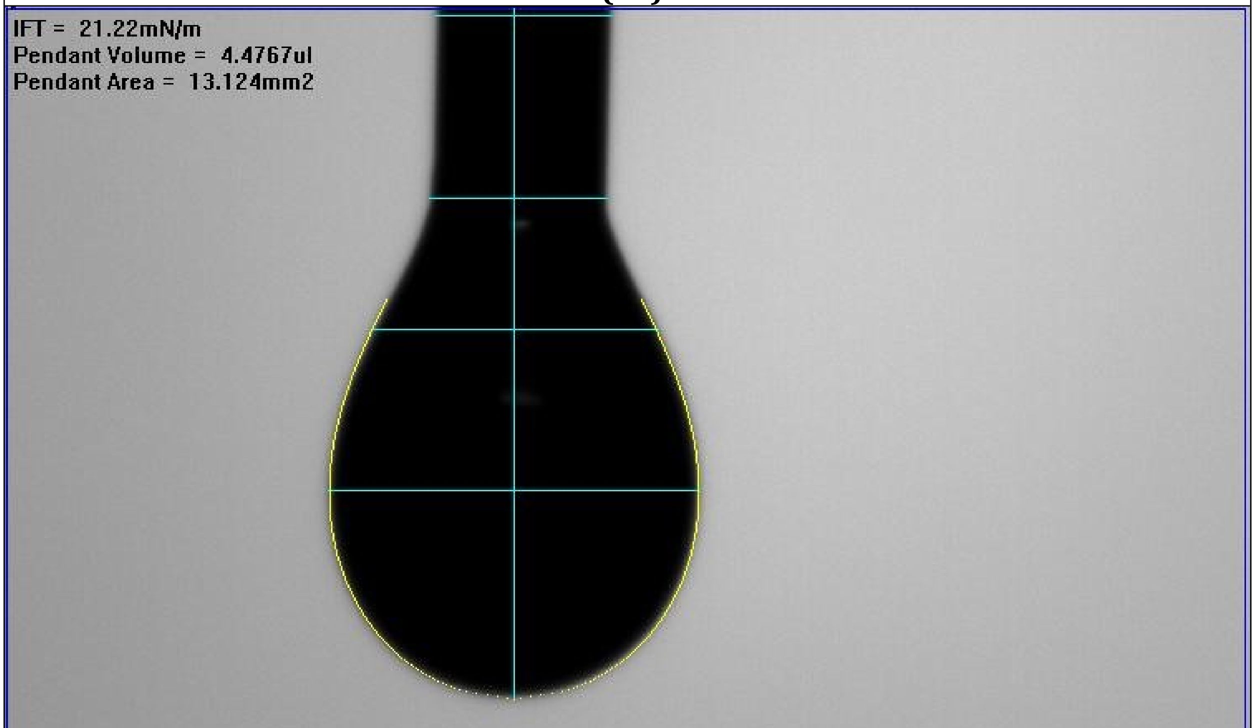


Figure S-8. *Surface Tension (ST) of Black 60 ink measured with the instrument First Ten Angstroms FTA200 using Pendant Drop Method.*

Wetting or Contact Angle of Black 60 ink on White PET:

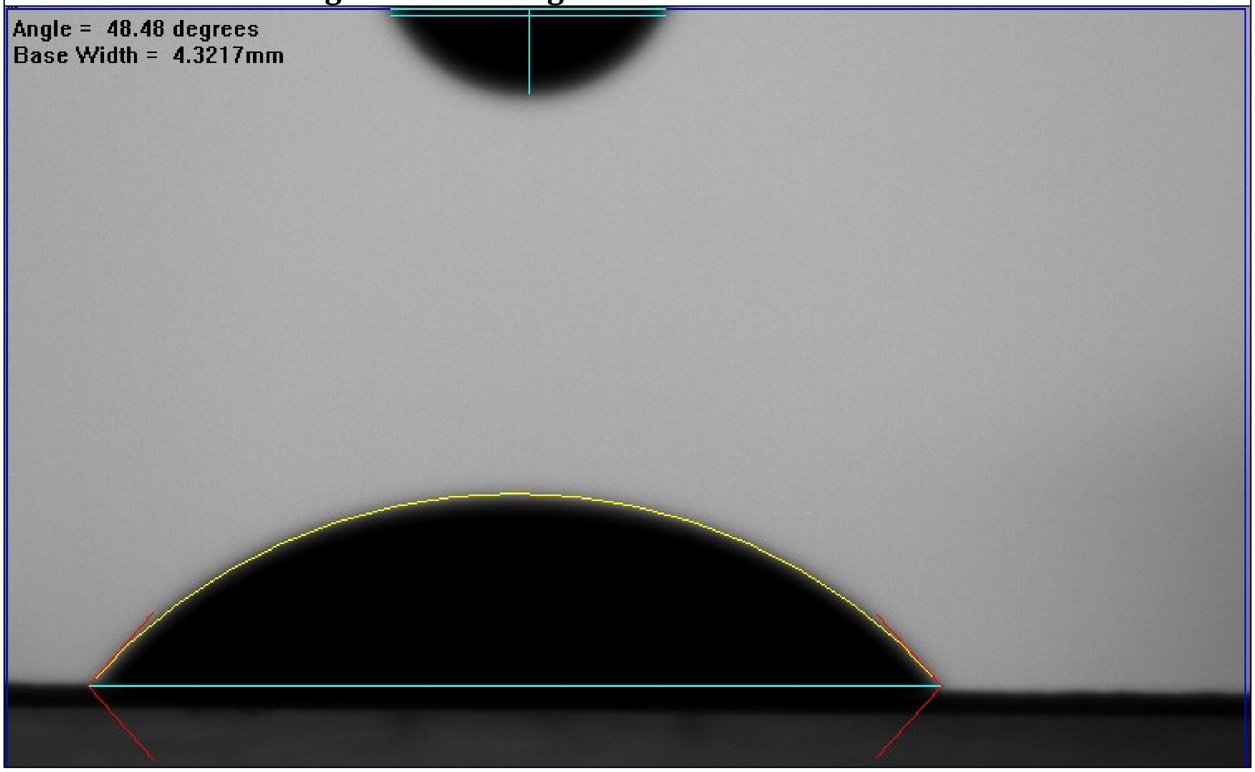


Figure S-9. *Contact Angle of Black 60 ink on White PET plastic surface. Measured with the instrument First Ten Angstroms FTA200 using Sessile Drop Method.*

Wetting or Contact Angle of Black 60 ink on Clear PET:

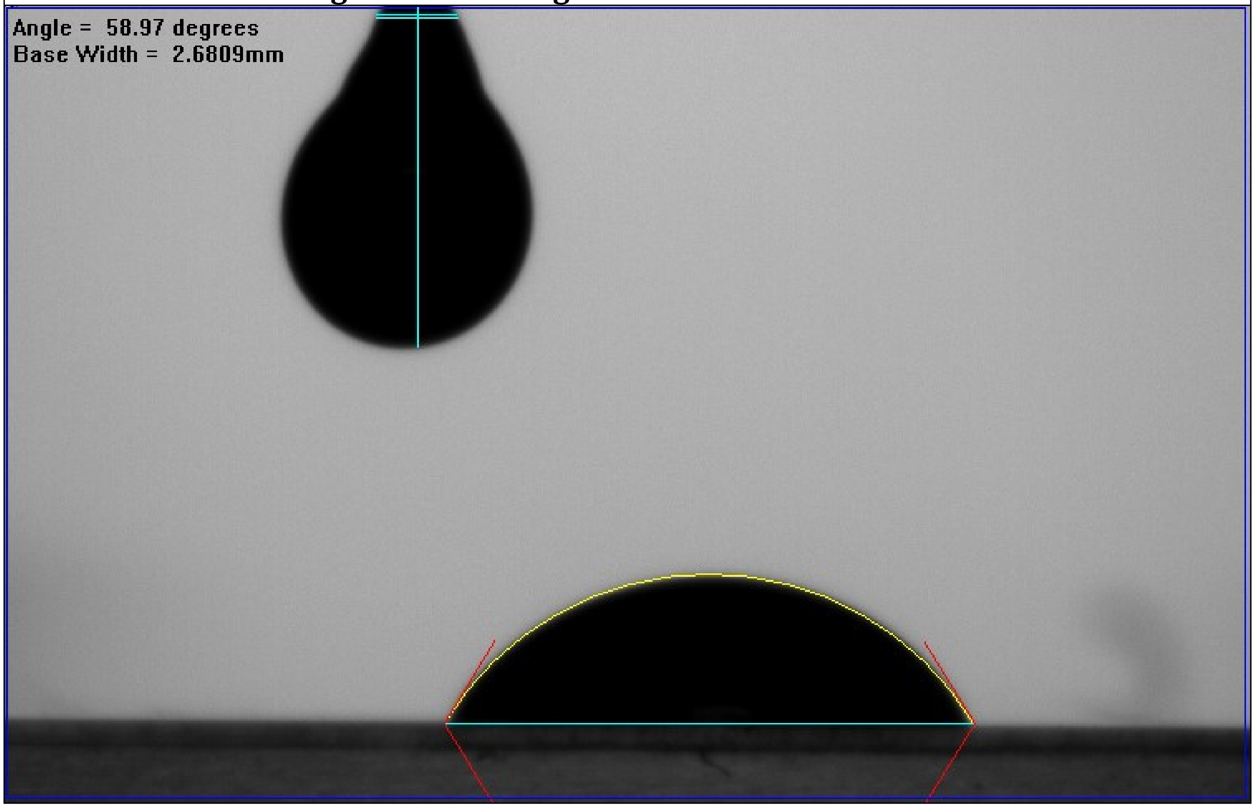


Figure S-10. *Contact Angle of Black 60 ink on Clear PET plastic surface. Measured with the instrument First Ten Angstroms FTA200 using Sessile Drop Method.*

Wetting or Contact Angle of ECI 7007 ink on White PET:

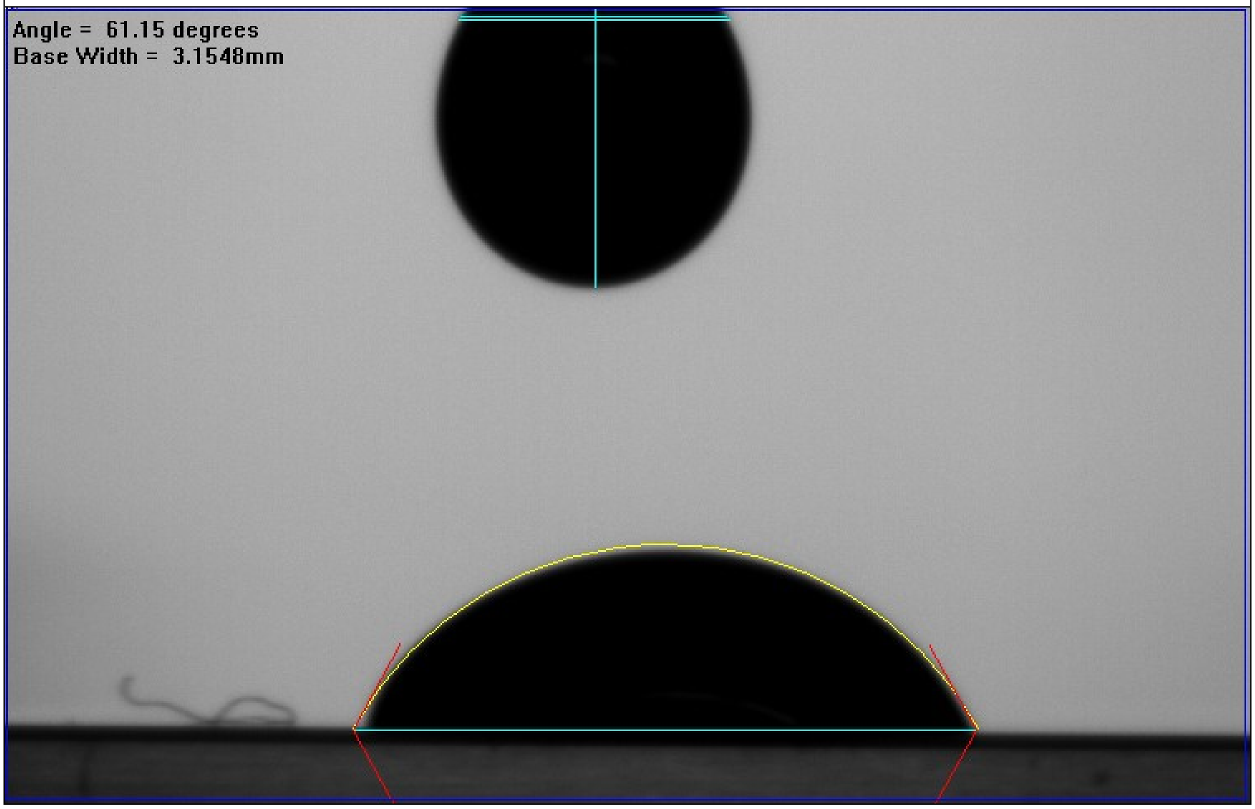


Figure S-11. *Contact Angle of ECI 7007 ink on White PET plastic surface. Measured with the instrument First Ten Angstroms FTA200 using Sessile Drop Method.*

Wetting or Contact Angle of ECI 7007 ink on Clear PET:

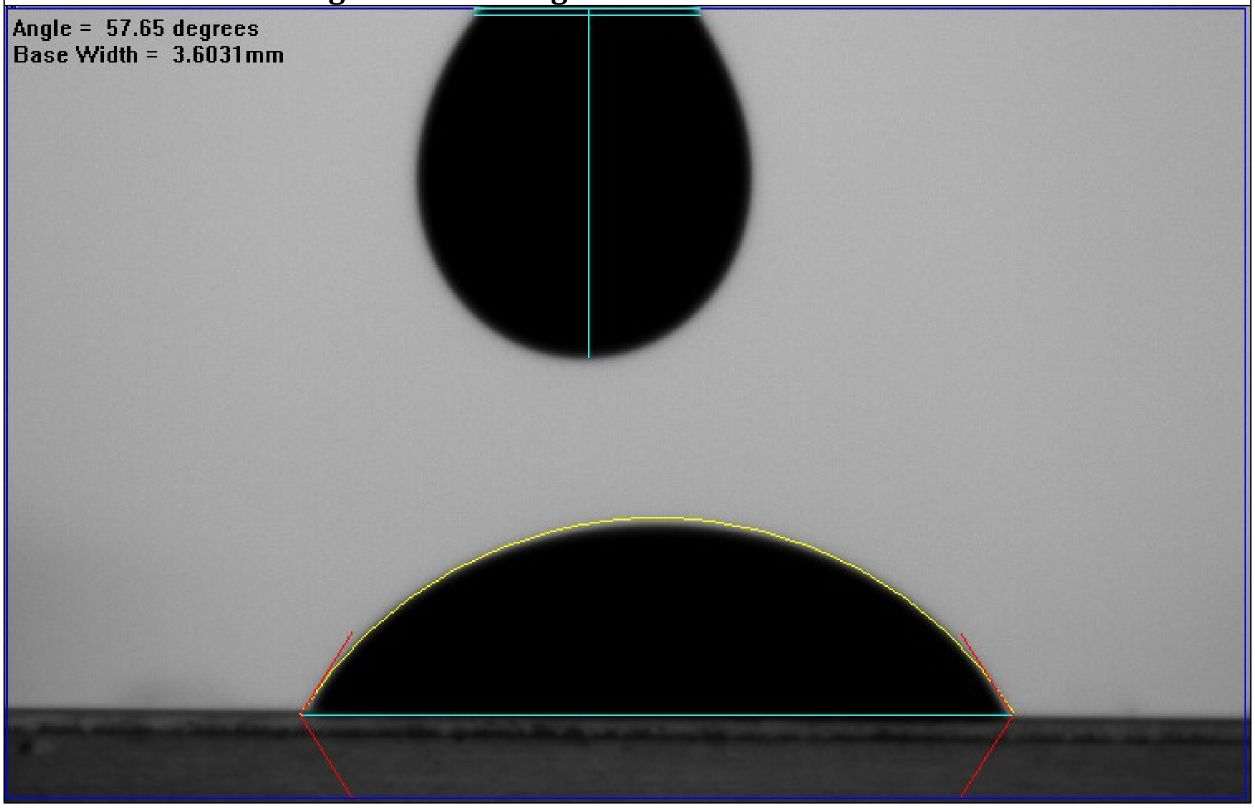


Figure S-12. *Contact Angle of ECI 7007 ink on Clear PET plastic surface. Measured with the instrument First Ten Angstroms FTA200 using Sessile Drop Method.*

Wetting or Contact Angle of Black 60 ink on chrome:

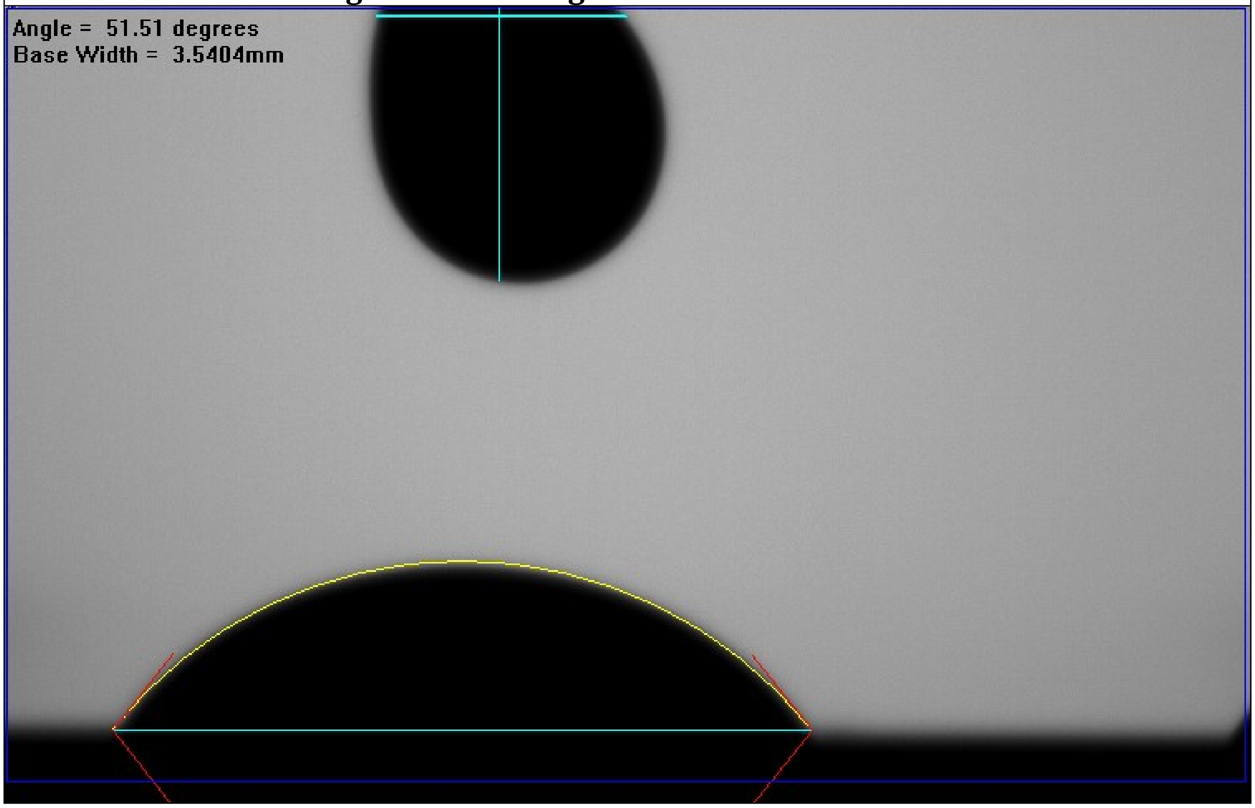


***Figure S-13**. Contact Angle of Black 60 ink on chrome surface. Measured with the instrument First Ten Angstroms FTA200 using Sessile Drop Method.*

Wetting or Contact Angle of Black 60 ink on standard DLC:

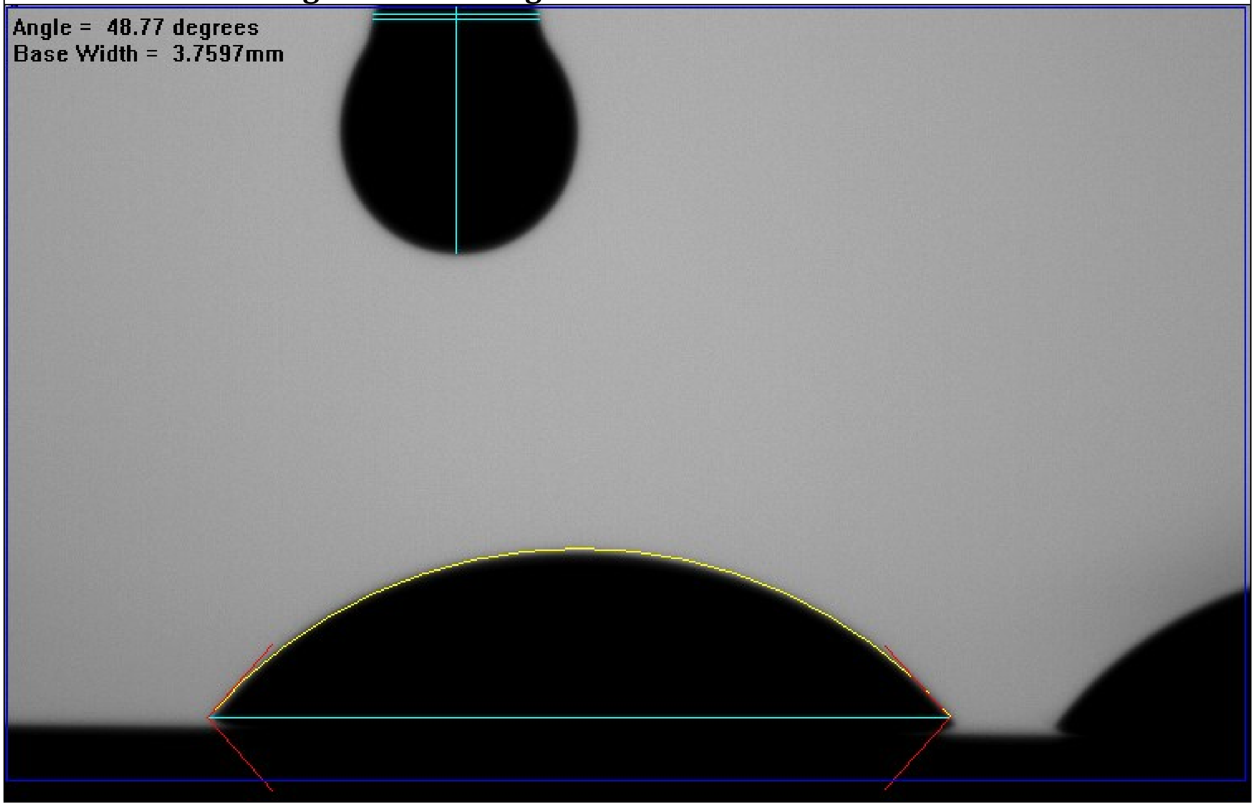


Figure S-14*. Contact Angle of Black 60 ink on standard DLC surface. Measured with the instrument First Ten Angstroms FTA200 using Sessile Drop Method.*

Wetting or Contact Angle of ECI 7007 ink on chrome:

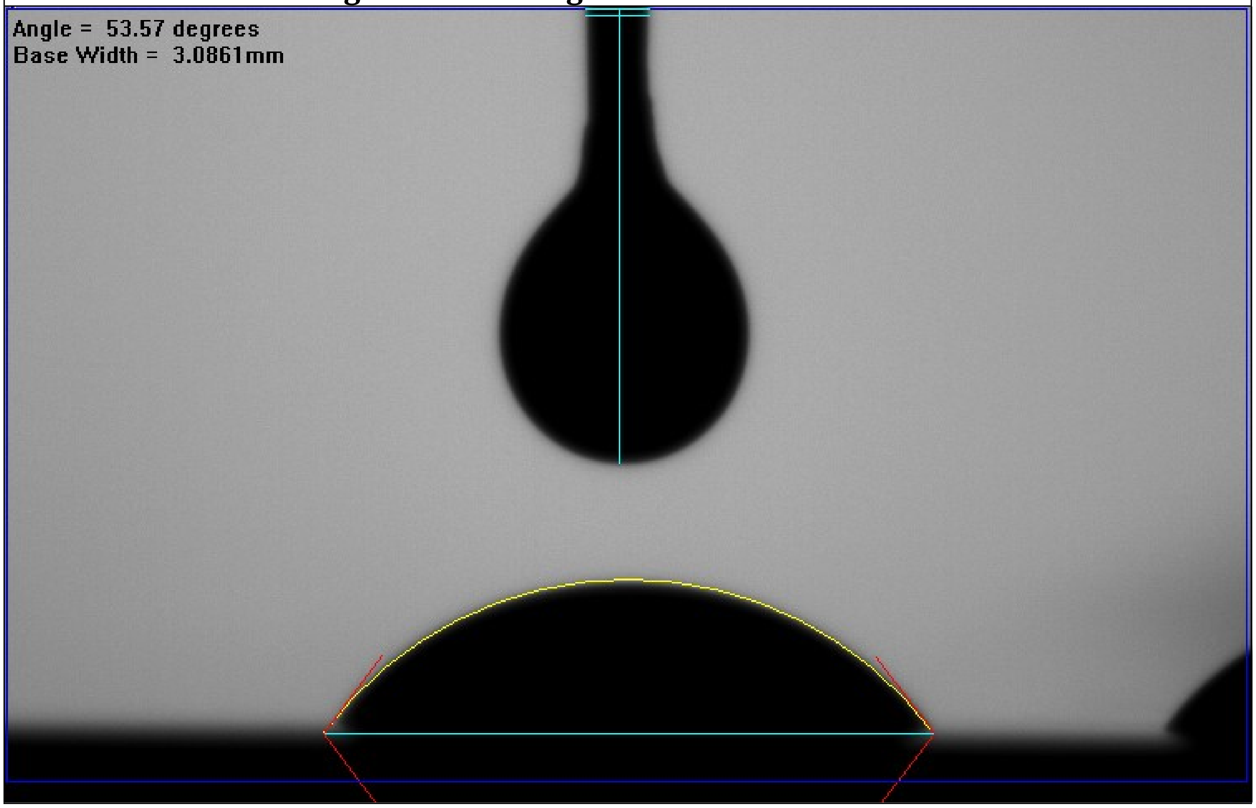


Figure S-15. *Contact Angle of ECI 7007 ink on chrome surface. Measured with the instrument First Ten Angstroms FTA200 using Sessile Drop Method.*

Wetting or Contact Angle of ECI 7007 ink on standard DLC:

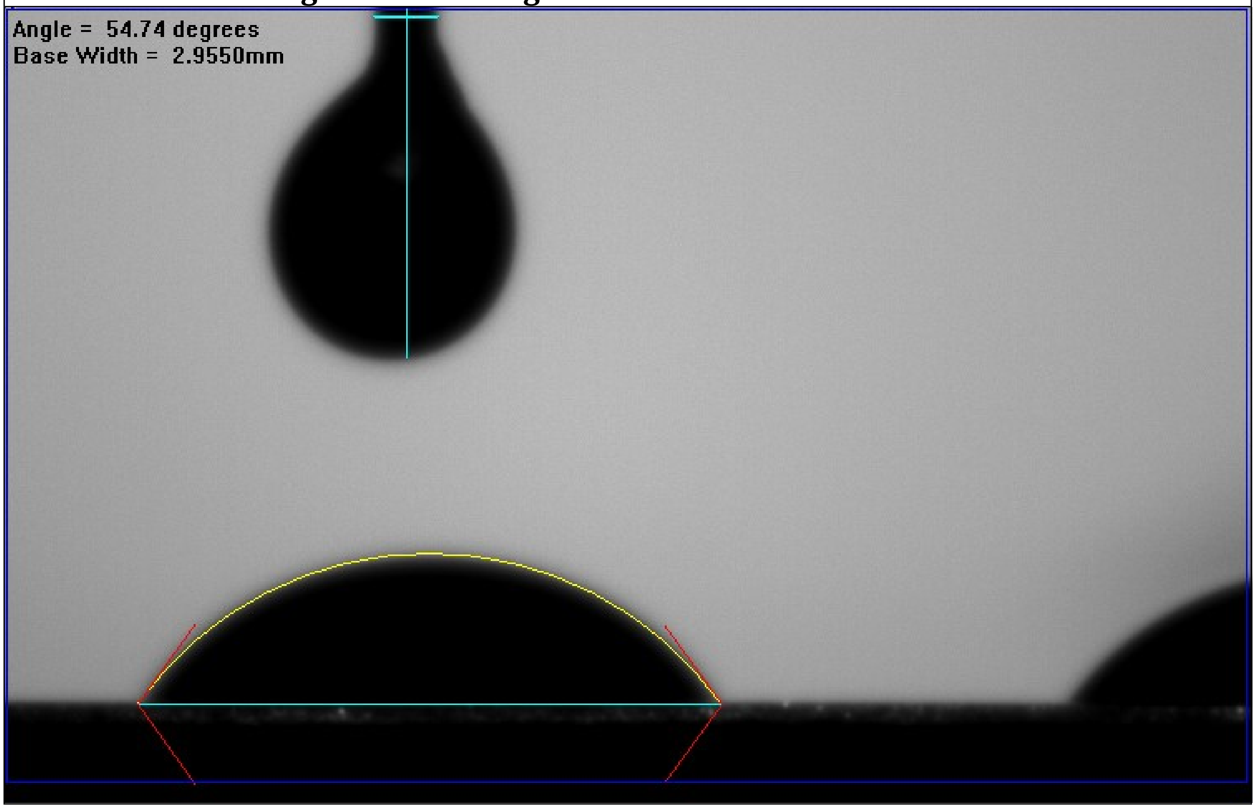


Figure S-16. *Contact Angle of ECI 7007 ink on standard DLC surface. Measured with the instrument First Ten Angstroms FTA200 using Sessile Drop Method.*

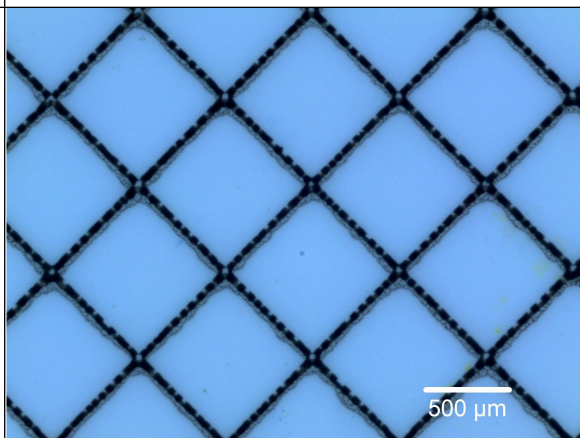
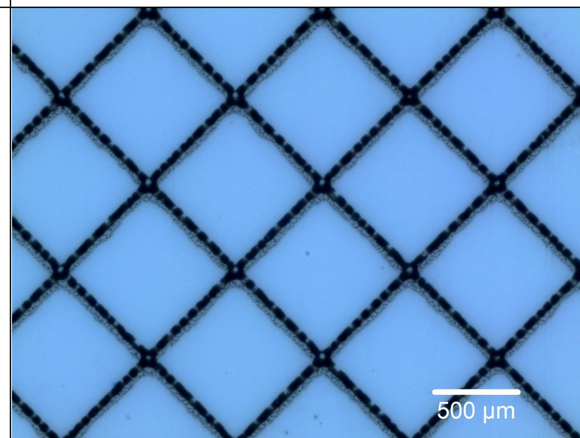
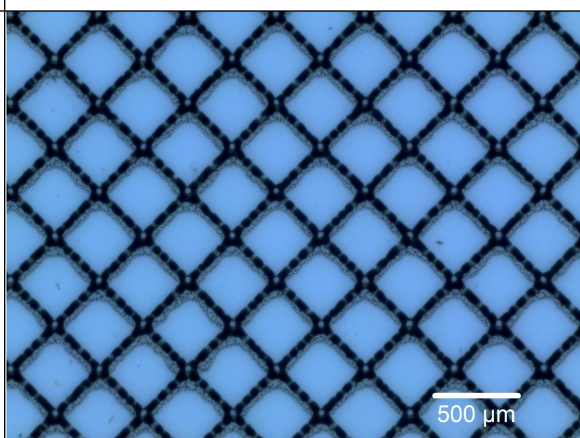
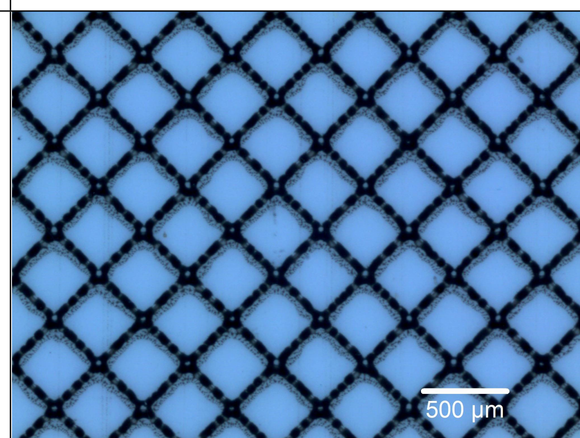
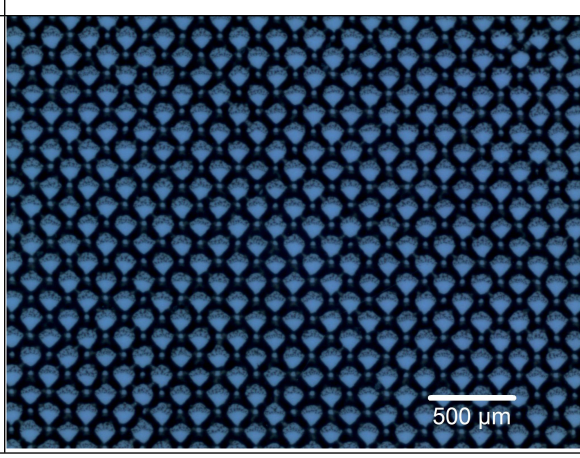
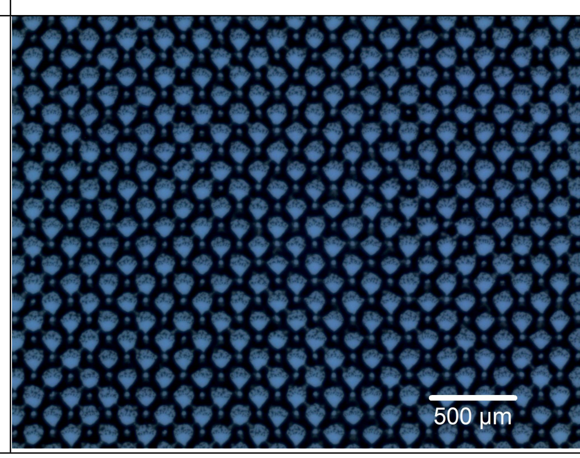
Grid Space (µm)	Trial One (T1) Print Experiment - 20 µm Grid (Blade Type: Metal, Ink Type: Black60, Substrate Type: White PET)	
	chrome	*Standard DLC*
1000 µm		
500 µm		
200 µm		

Figure S-17. *Trial One Print Experiment- 20 µm Grid (Blade Type: Metal, Ink Type: Black60, Substrate Type: White PET).*

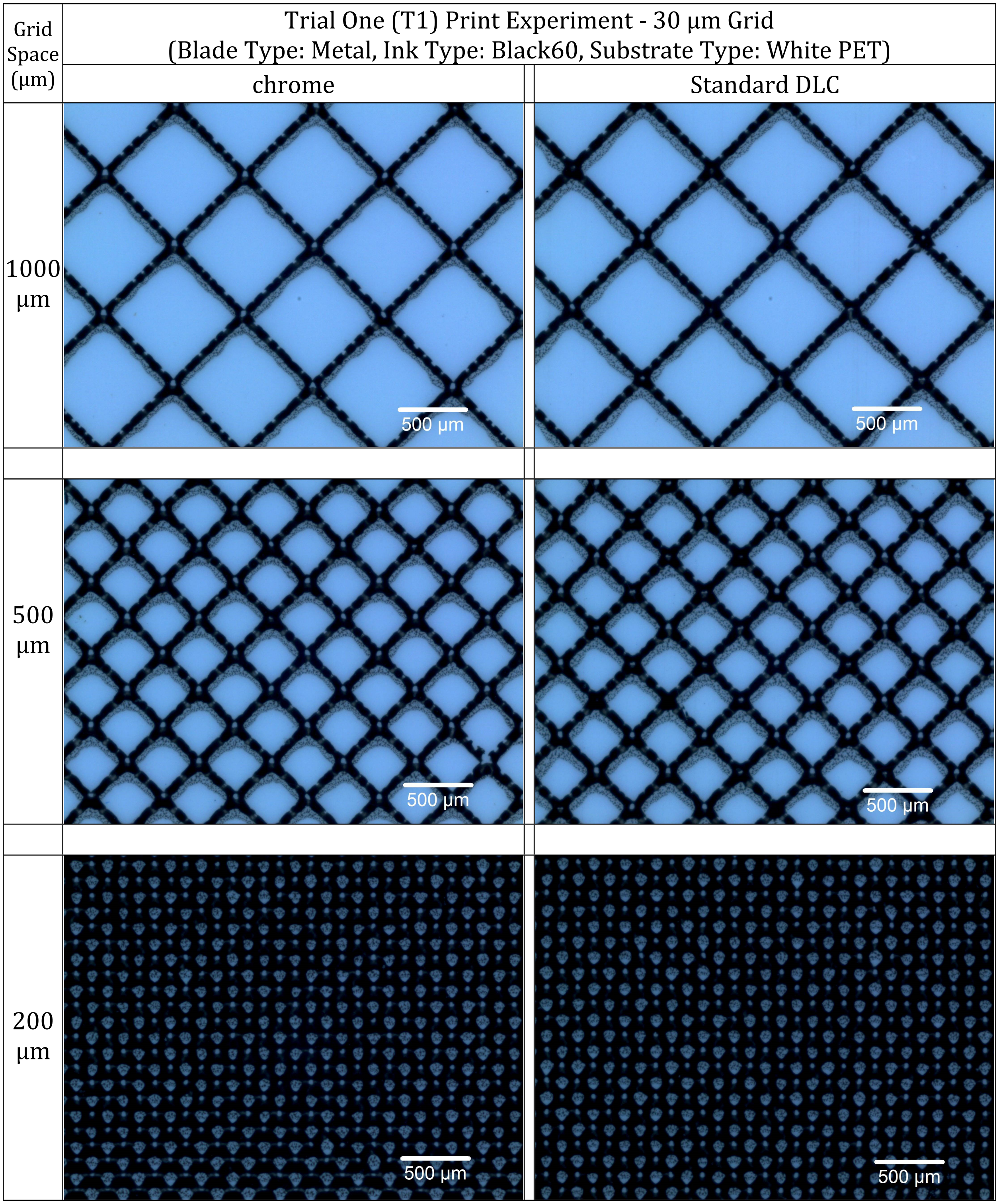


Figure S-18*. Trial One Print Experiment- 30 µm Grid (Blade Type: Metal, Ink Type: Black60, Substrate Type: White PET).*

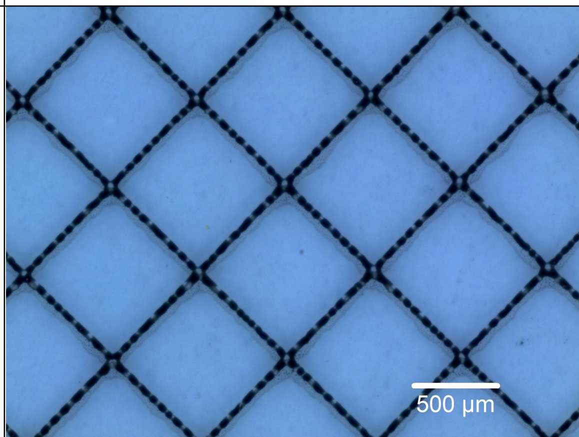
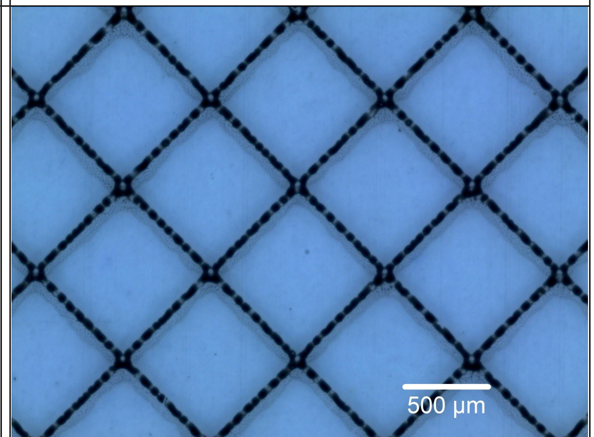
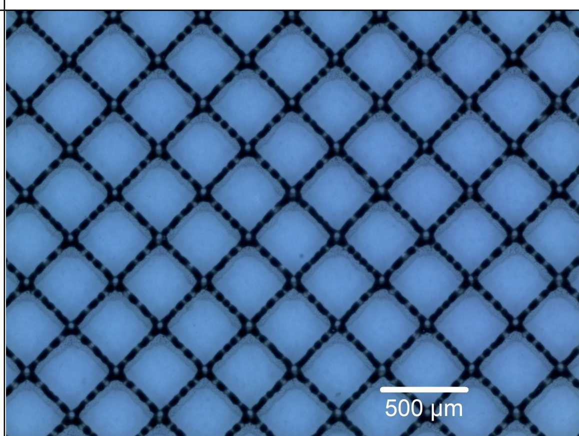
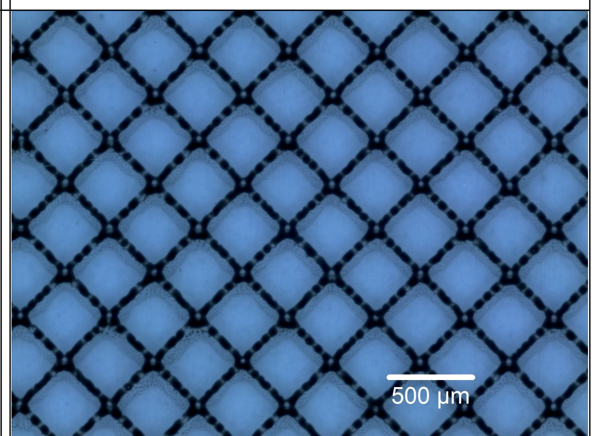
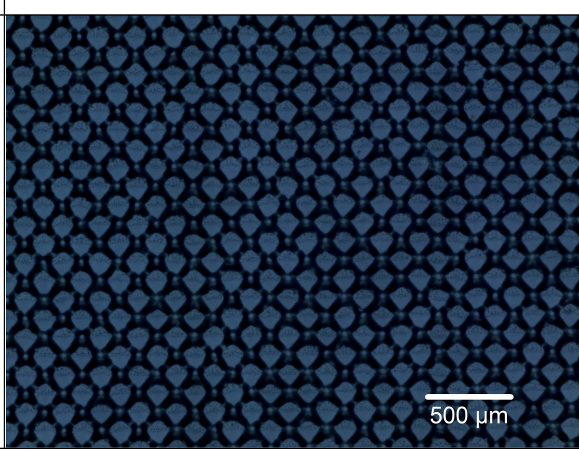
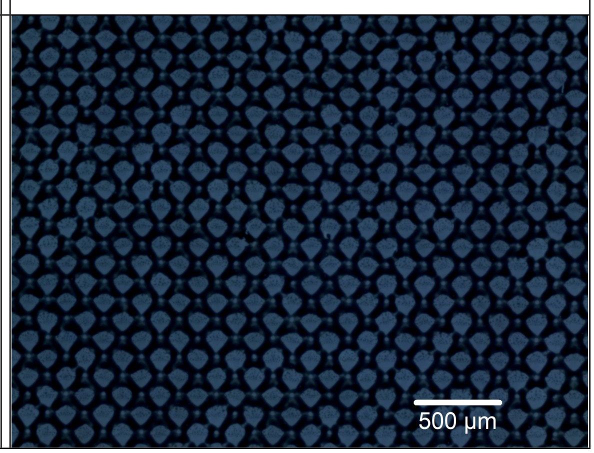
Grid Space (µm)	Trial Two (T2) Print Experiment - 20 µm Grid (Blade Type: Metal, Ink Type: Black60, Substrate Type: Clear PET)	
	chrome	Standard DLC
1000 µm		
500 µm		
200 µm		

Figure S-19. *Trial Two Print Experiment - 20 µm Grid (Blade Type: Metal, Ink Type: Black60, Substrate Type: Clear PET).*

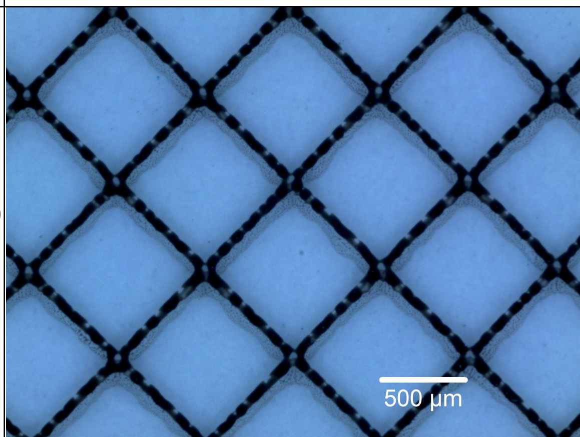
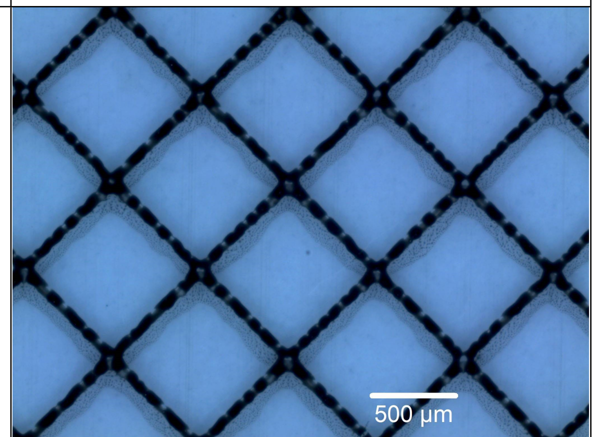
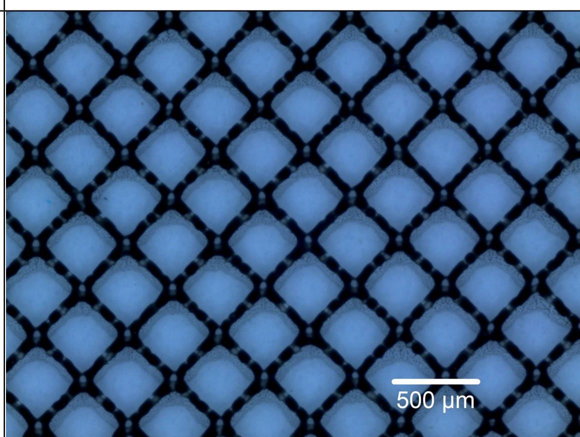
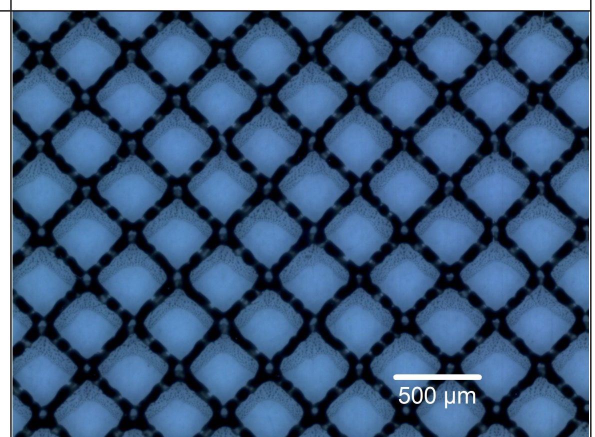
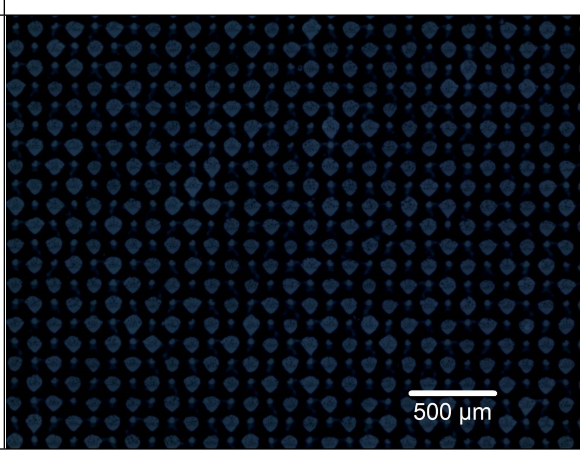
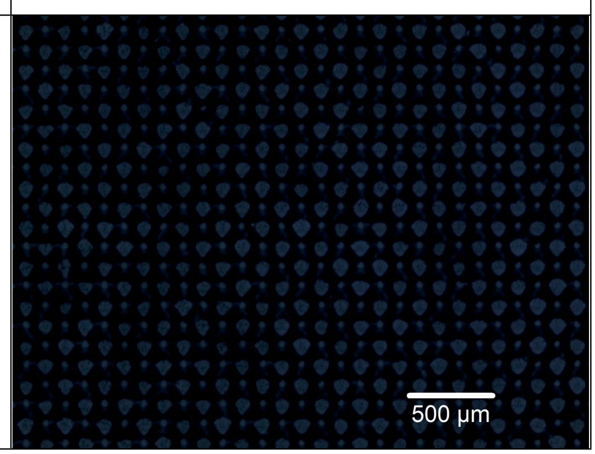
Grid Space (µm)	Trial Two (T2) Print Experiment - 30 µm Grid (Blade Type: Metal, Ink Type: Black60, Substrate Type: Clear PET)	
	chrome	Standard DLC
1000 µm		
500 µm		
200 µm		

Figure S-20. *Trial Two Print Experiment - 30 µm Grid (Blade Type: Metal, Ink Type: Black60, Substrate Type: Clear PET).*

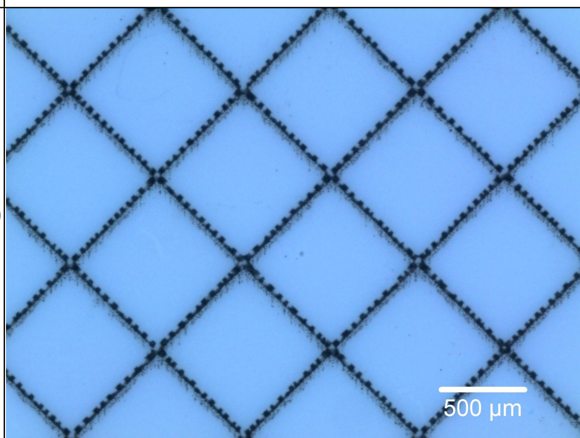
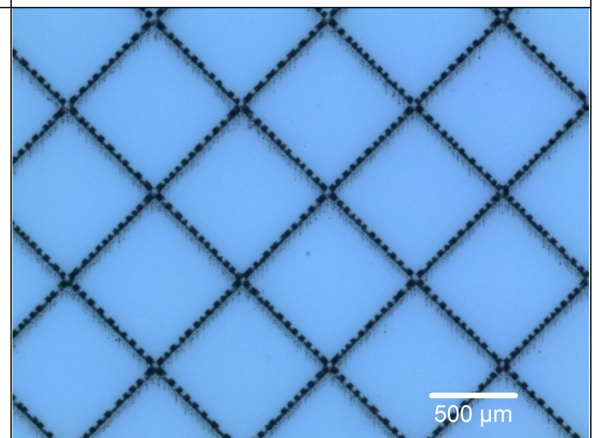
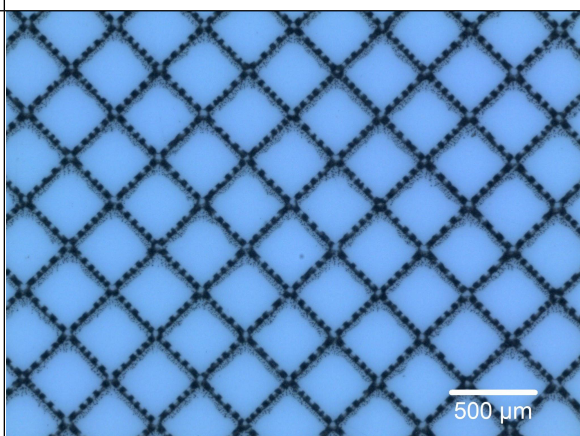
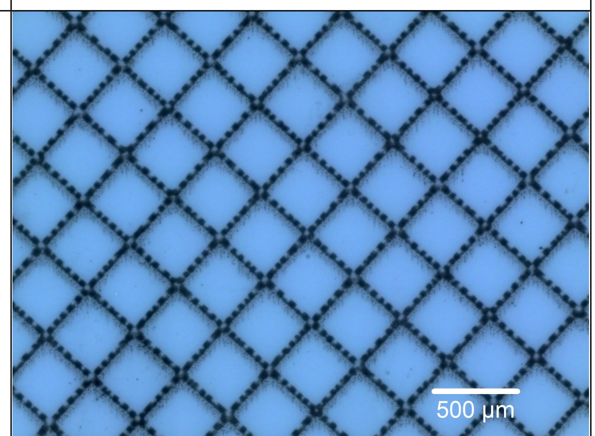
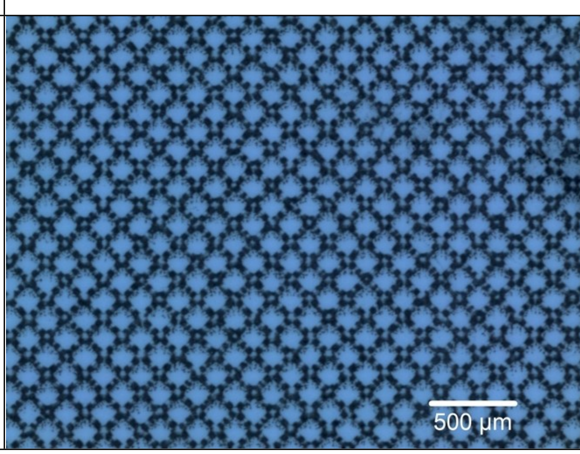
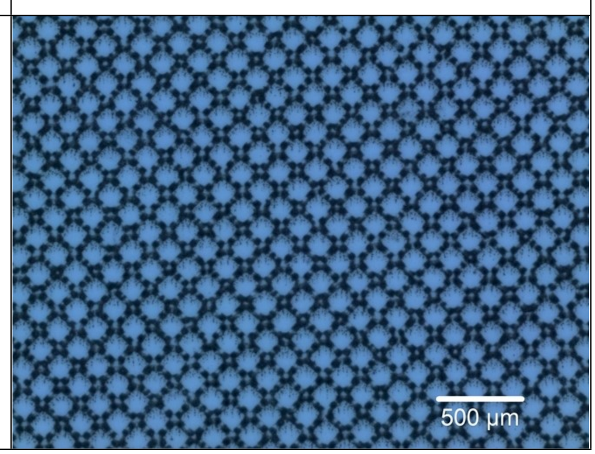
Grid Space (µm)	Trial Three (T3) Print Experiment - 20 µm Grid (Blade Type: Metal, Ink Type: ECI7007, Substrate Type: White PET)	
	chrome	Standard DLC
1000 µm		
500 µm		
200 µm		

Figure S-21*. Trial Three Print Experiment - 20 µm Grid (Blade Type: Metal, Ink Type: ECI7007, Substrate Type: White PET).*

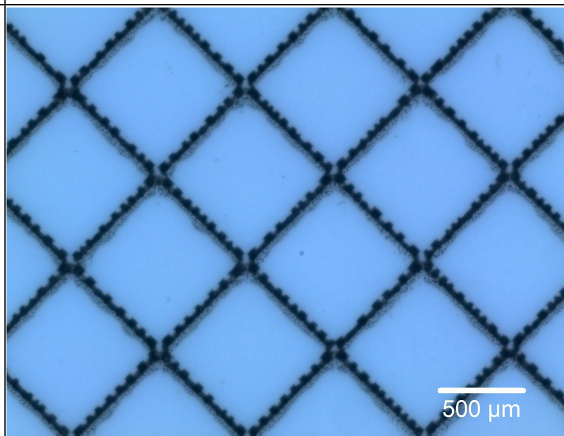
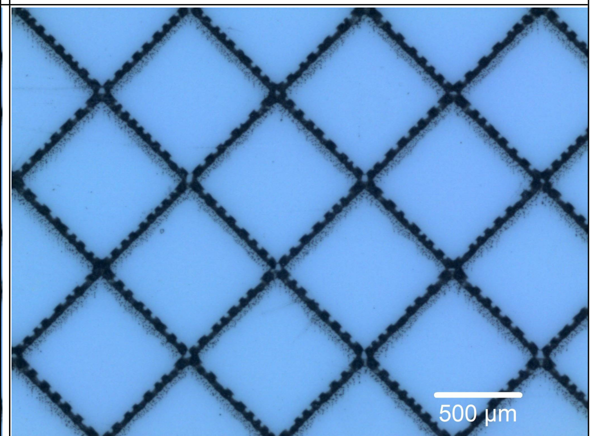
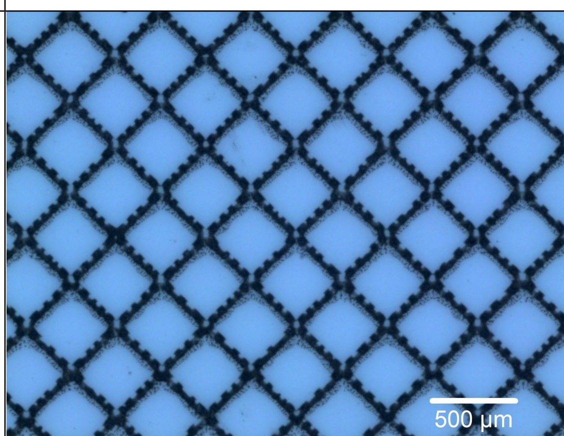
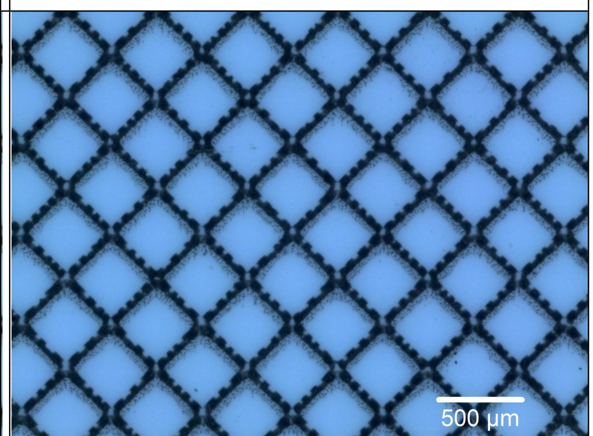
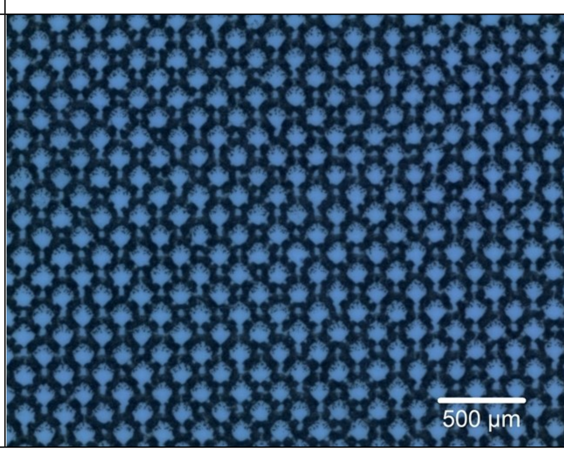
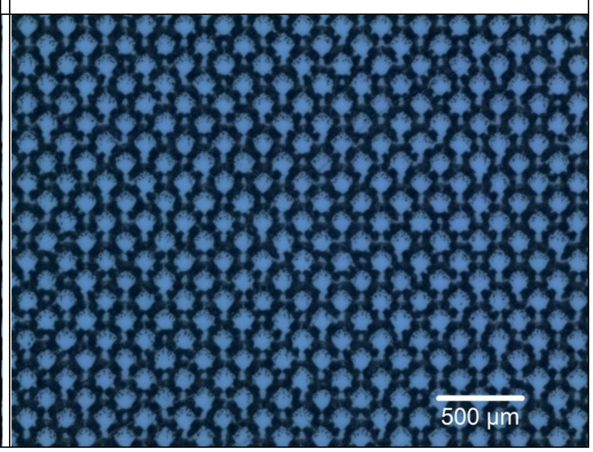
<table>
<tr><td rowspan="2">Grid Space (µm)</td><td colspan="2">Trial Three (T3) Print Experiment - 30 µm Grid
(Blade Type: Metal, Ink Type: ECI7007, Substrate Type: White PET)</td></tr>
<tr><td>chrome</td><td>Standard DLC</td></tr>
<tr><td>Space 1000 µm</td><td></td><td></td></tr>
<tr><td>Space 500 µm</td><td></td><td></td></tr>
<tr><td>Space 200 µm</td><td></td><td></td></tr>
</table>

Figure S-22. *Trial Three Print Experiment - 30 µm Grid (Blade Type: Metal, Ink Type: ECI7007, Substrate Type: White PET).*

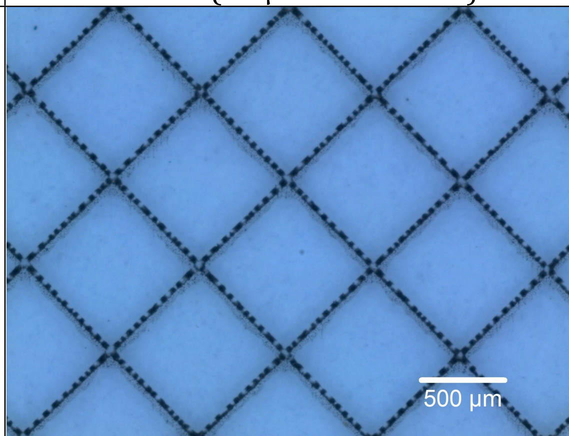
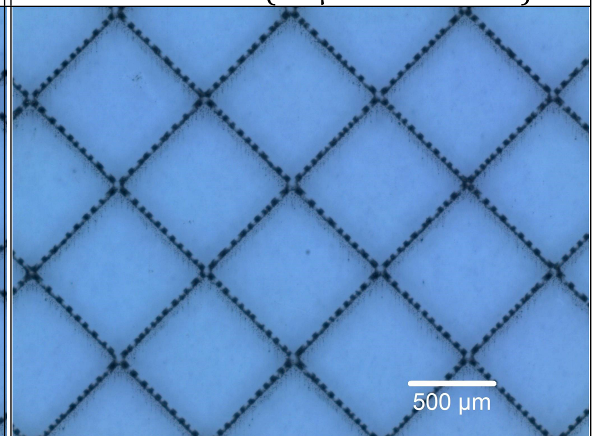
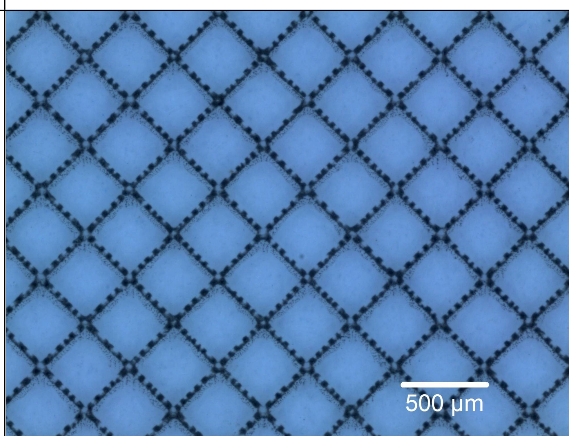
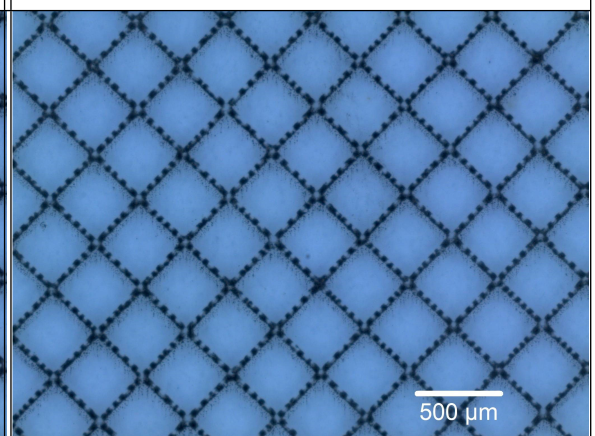
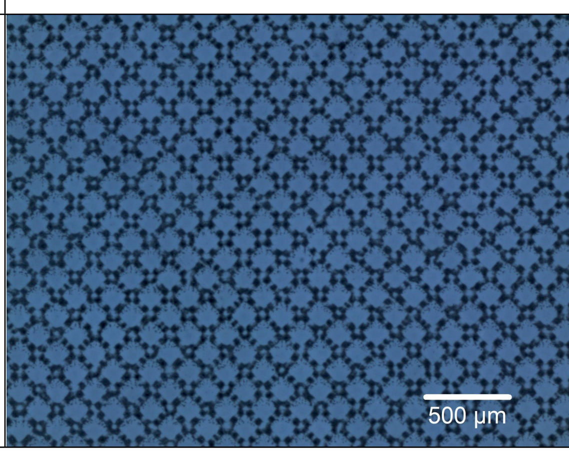
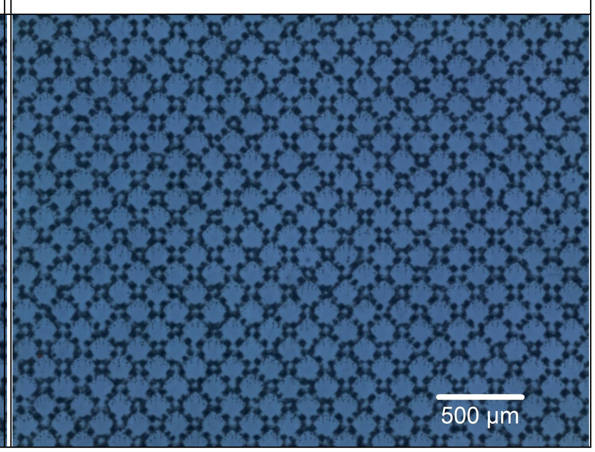
Grid Space (µm)	Trial Four (T4) Print Experiment - 20 µm Grid (Blade Type: Metal, Ink Type: ECI7007, Substrate Type: Clear PET)	
	chrome (20 µm Line Width)	Standard DLC (20 µm Line Width)
Space 1000 µm		
Space 500 µm		
Space 200 µm		

Figure S-23. *Trial Four Print Experiment - 20 µm Grid (Blade Type: Metal, Ink Type: ECI7007, Substrate Type: Clear PET).*

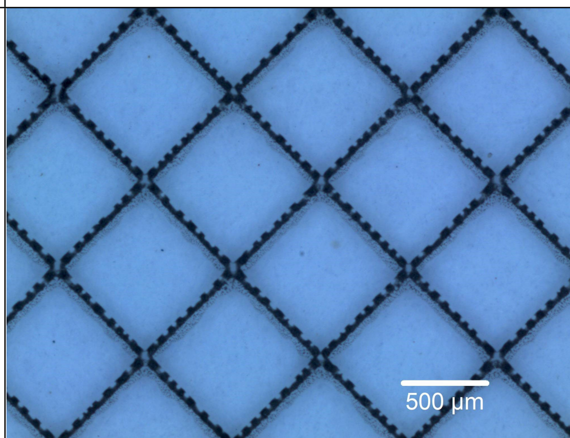
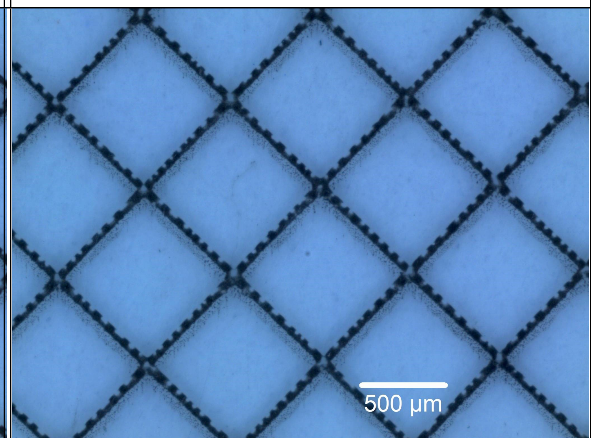
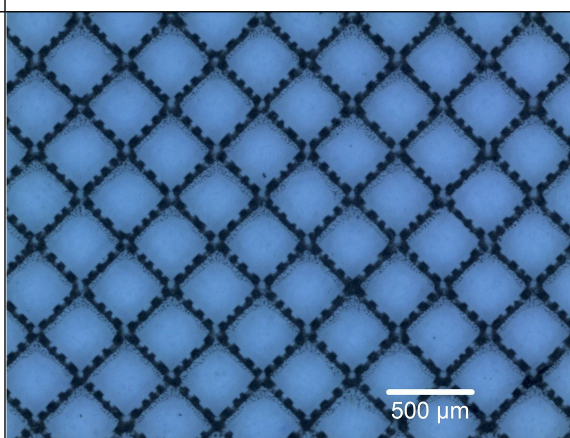
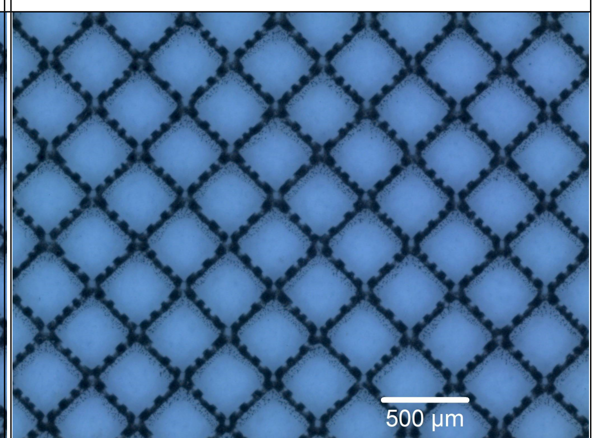
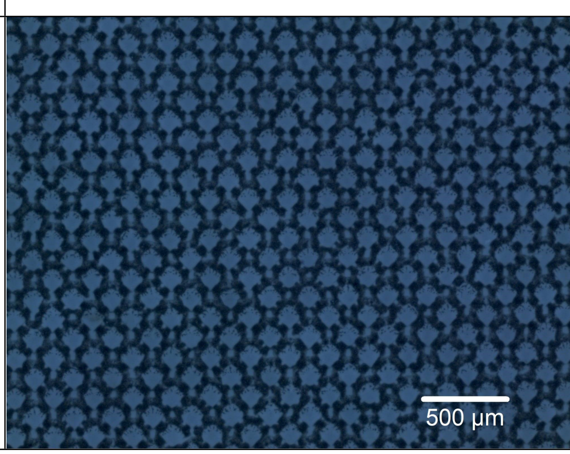
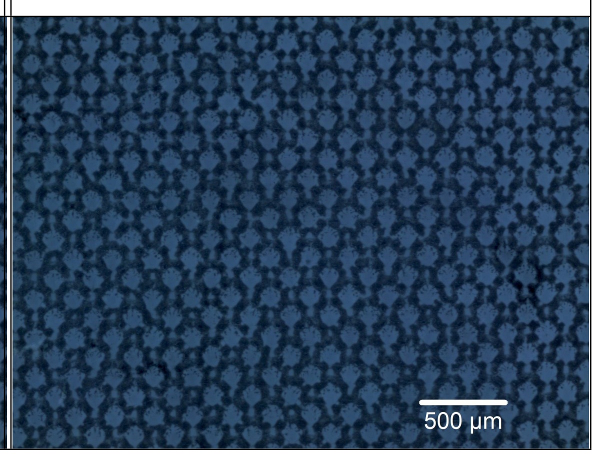
Grid Space (µm)	Trial Four (T4) Print Experiment - 30 µm Grid (Blade Type: Metal, Ink Type: ECI7007, Substrate Type: Clear PET)	
	chrome	Standard DLC
Space 1000 µm		
Space 500 µm		
Space 200 µm		

Figure S-24*. Trial Four Print Experiment - 30 µm Grid (Blade Type: Metal, Ink Type: ECI7007, Substrate Type: Clear PET).*

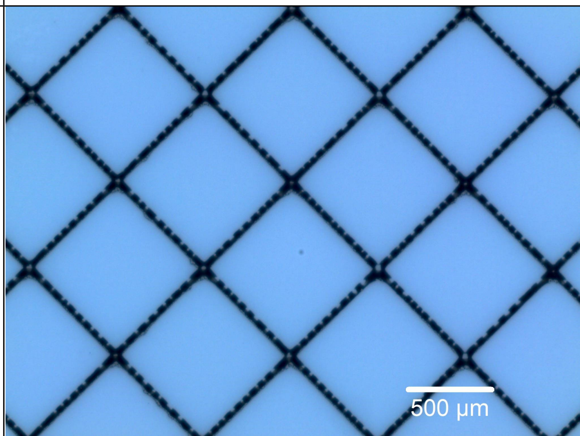
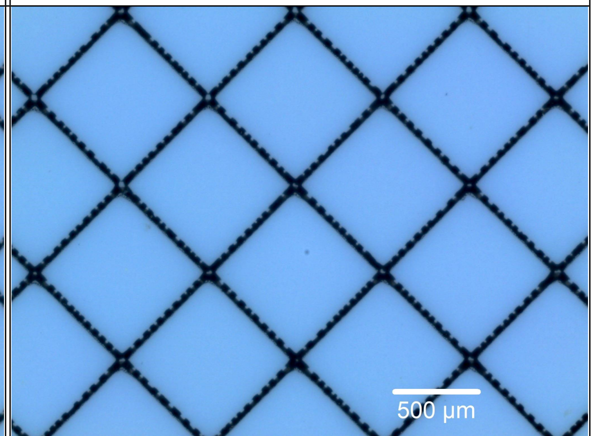
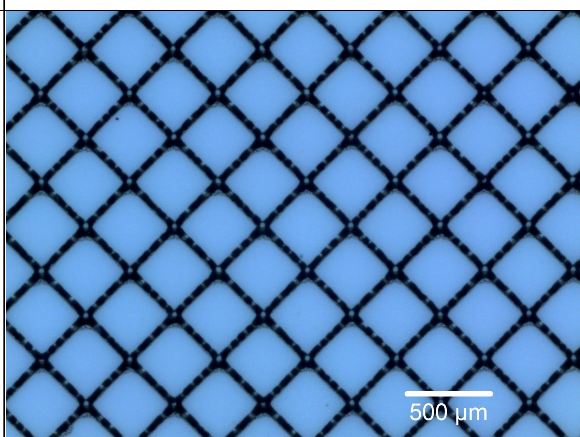
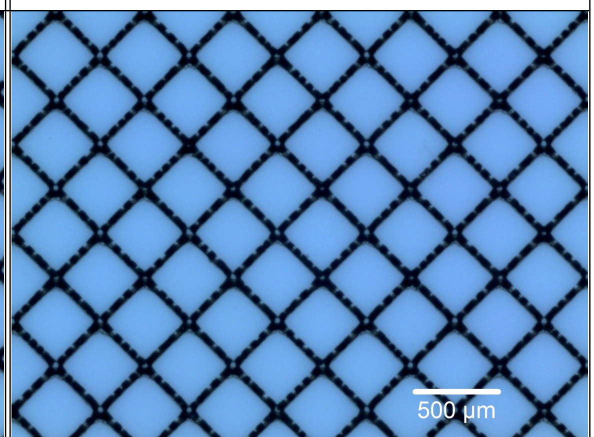
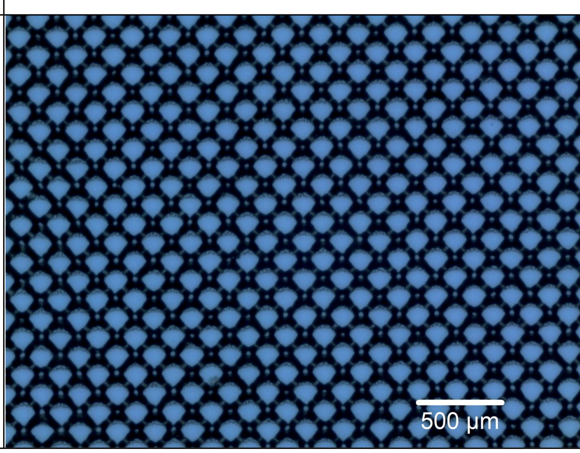
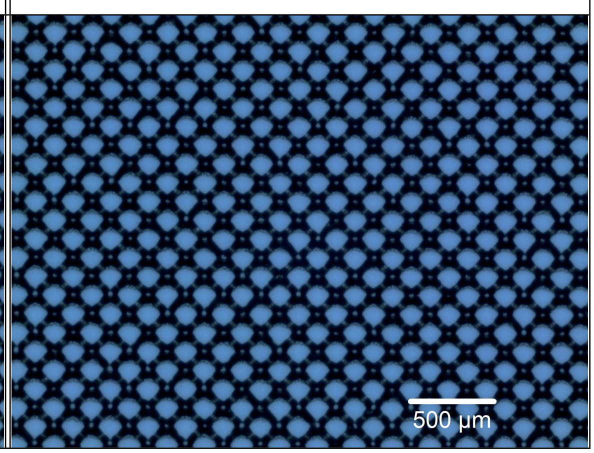
Grid Space (µm)	Trial Five (T5) Print Experiment - 20 µm Grid (Blade Type: Plastic, Ink Type: Black60, Substrate Type: White PET)	
	chrome	Standard DLC
Space 1000 µm		
Space 500 µm		
Space 200 µm		

Figure S-25*. Trial Five Print Experiment - 20 µm Grid (Blade Type: Plastic, Ink Type: Black60, Substrate Type: White PET).*

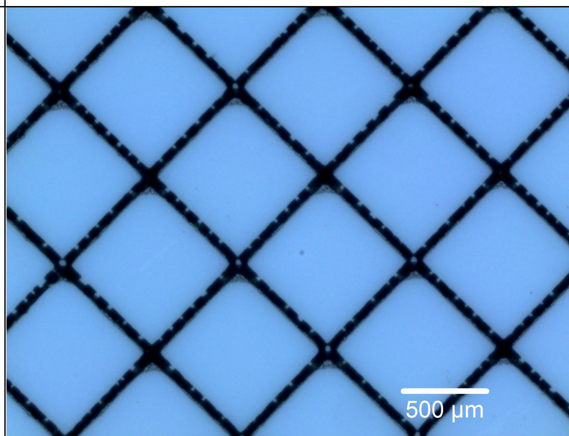
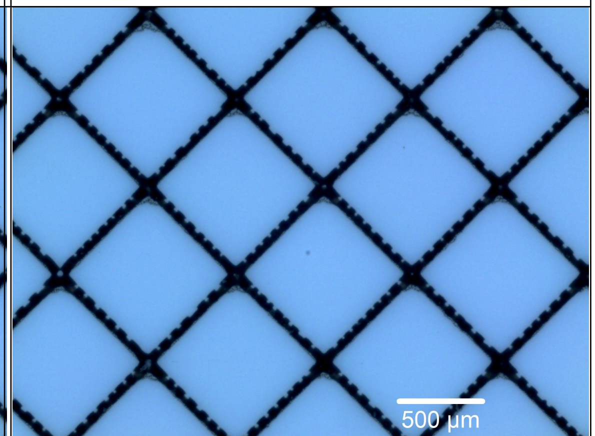
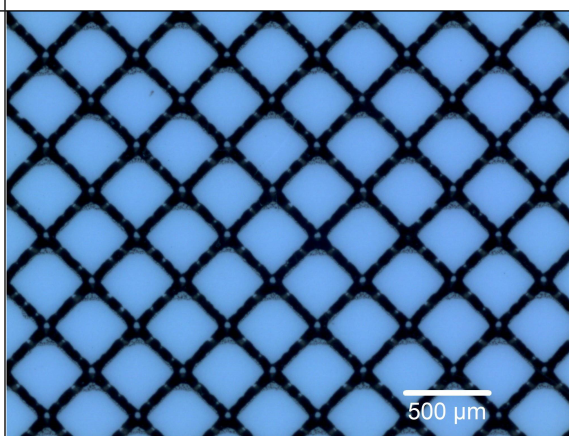
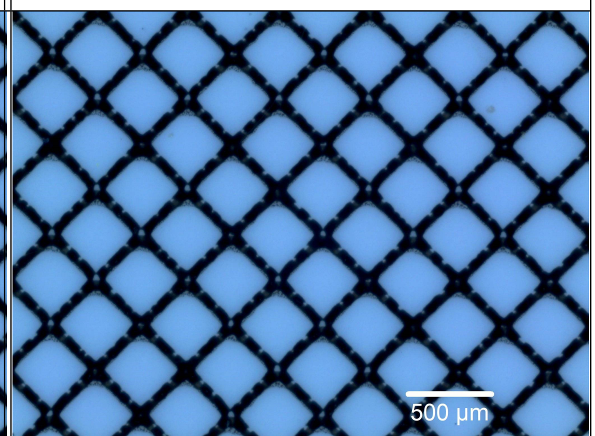
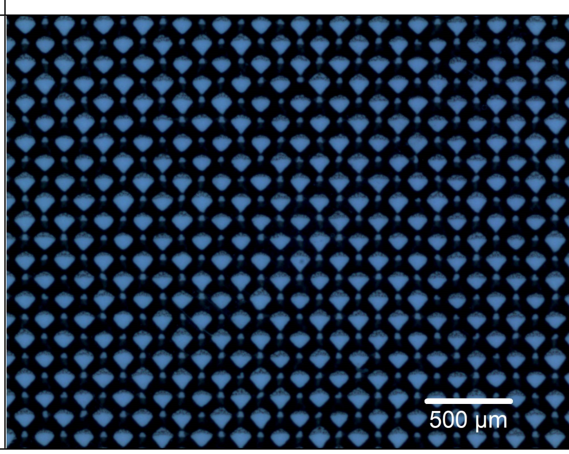
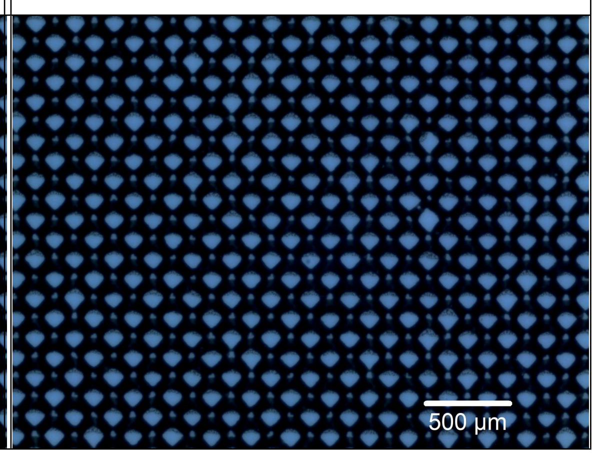
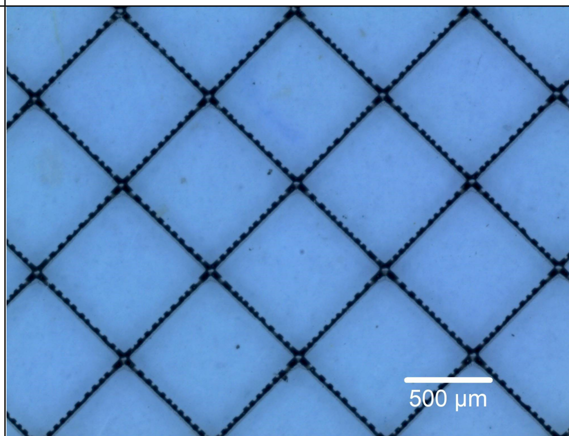
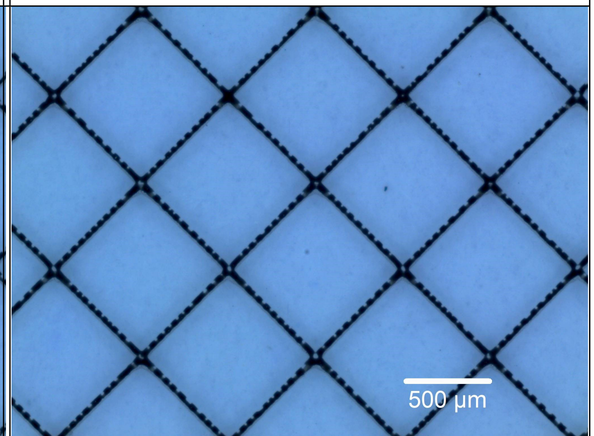
Grid Space (µm)	Trial Five (T5) Print Experiment - 30 µm Grid (Blade Type: Plastic, Ink Type: Black60, Substrate Type: White PET)	
	chrome	Standard DLC
Space 1000 µm		
Space 500 µm		
Space 200 µm		

Figure S-26. *Trial Five Print Experiment - 30 µm Grid (Blade Type: Plastic, Ink Type: Black60, Substrate Type: White PET).*

<table>
<tr><td rowspan="2">Grid Space (µm)</td><td colspan="2">Trial Six (T6) Print Experiment - 20 µm Grid
(Blade Type: Plastic, Ink Type: Black60, Substrate Type: Clear PET)</td></tr>
<tr><td>chrome</td><td>Standard DLC</td></tr>
<tr><td>Space 1000 µm</td><td>
</td><td>
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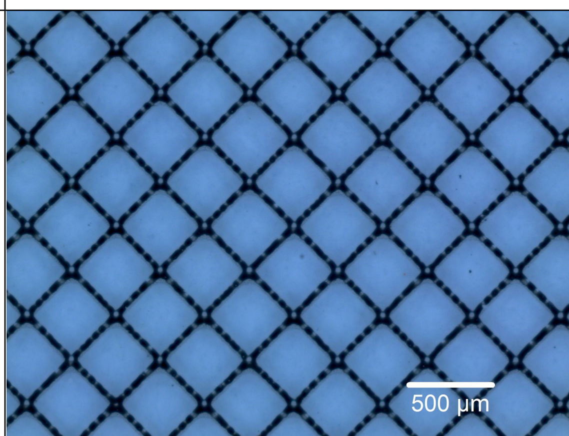
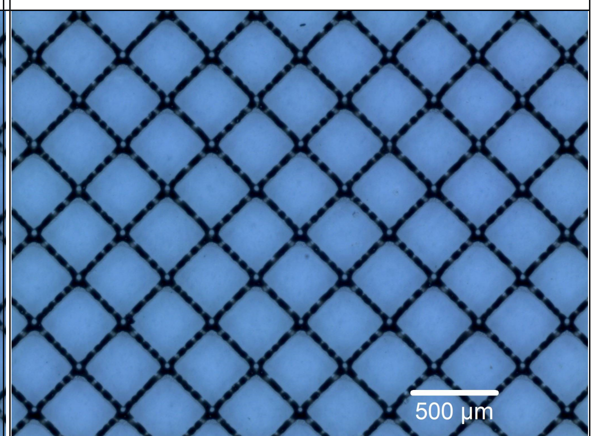
<tr><td>Space 500 µm</td><td>
</td><td>
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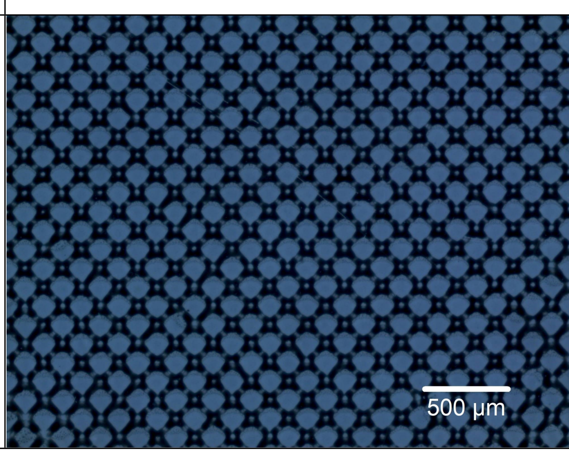
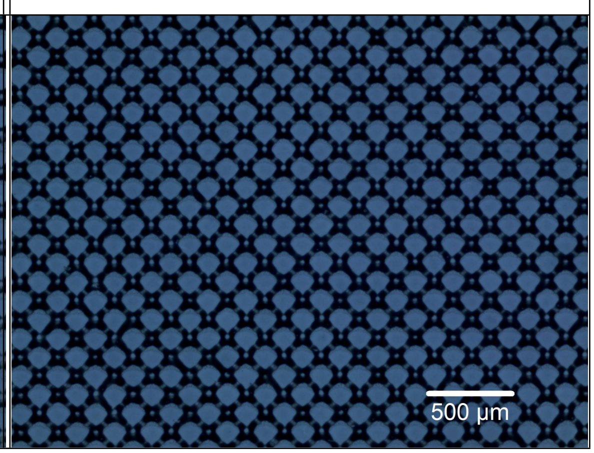
<tr><td></td><td></td><td></td></tr>
<tr><td>Space 200 µm</td><td>
</td><td>
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Figure S-27*. Trial Six Print Experiment - 20 µm Grid (Blade Type: Plastic, Ink Type: Black60, Substrate Type: Clear PET).*

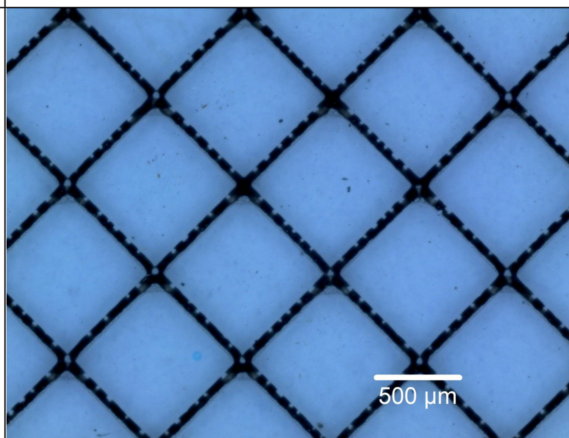
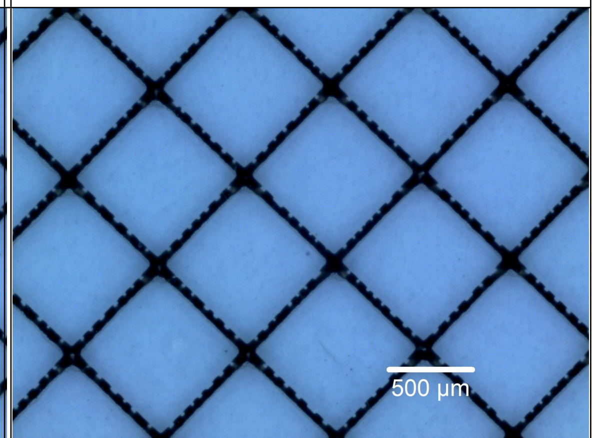
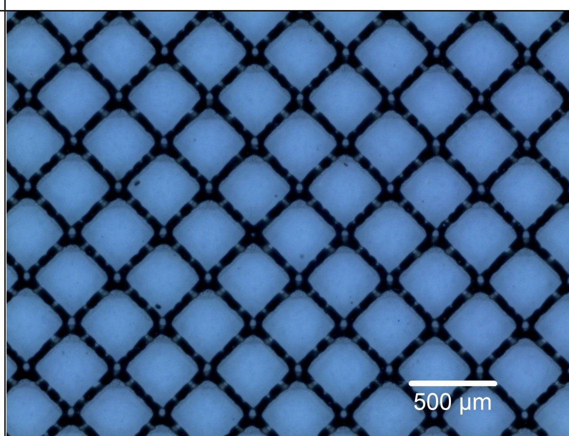
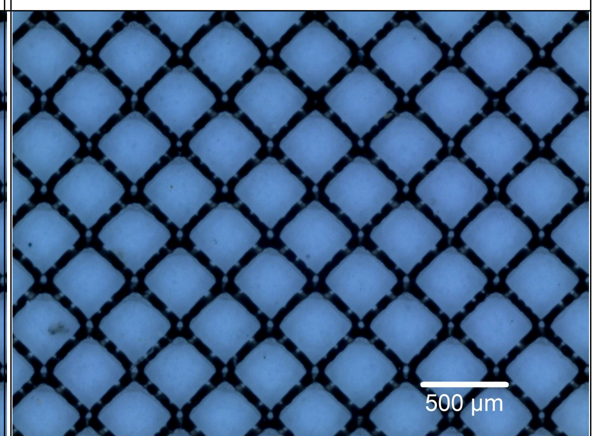
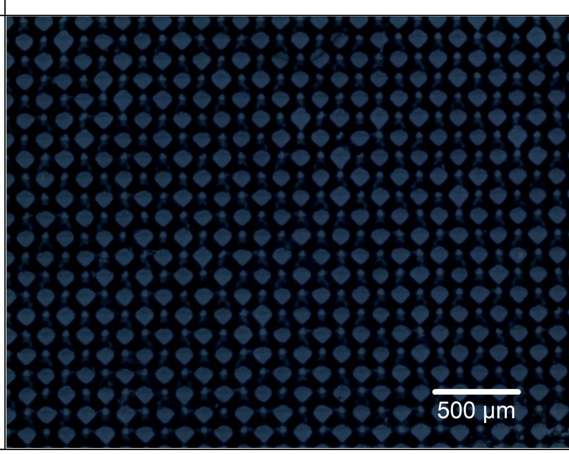
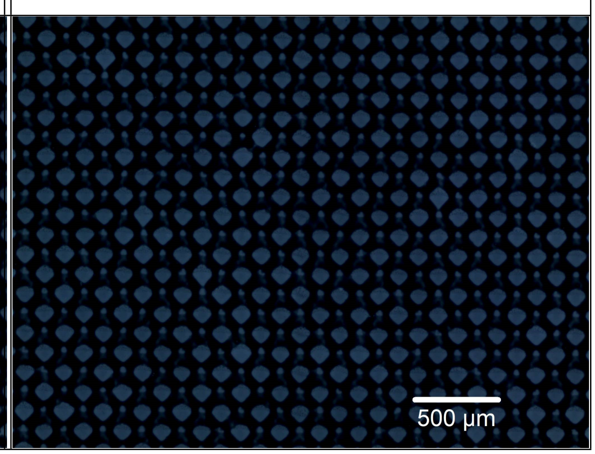
Grid Space (μm)	Trial Six (T6) Print Experiment - 30 μm Grid (Blade Type: Plastic, Ink Type: Black60, Substrate Type: Clear PET)	
	chrome	Standard DLC
Space 1000 μm		
Space 500 μm		
Space 200 μm		

Figure S-28. *Trial Six Print Experiment - 30 μm Grid (Blade Type: Plastic, Ink Type: Black60, Substrate Type: Clear PET).*

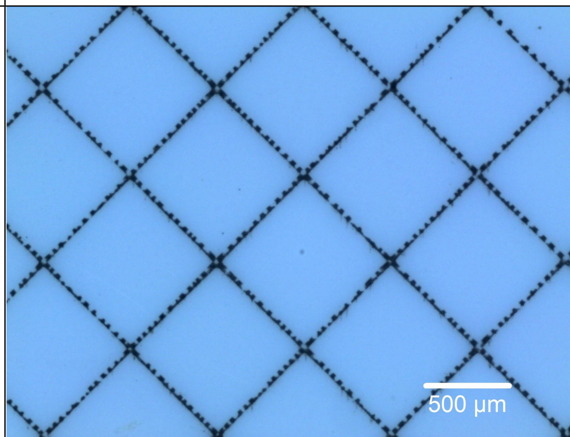
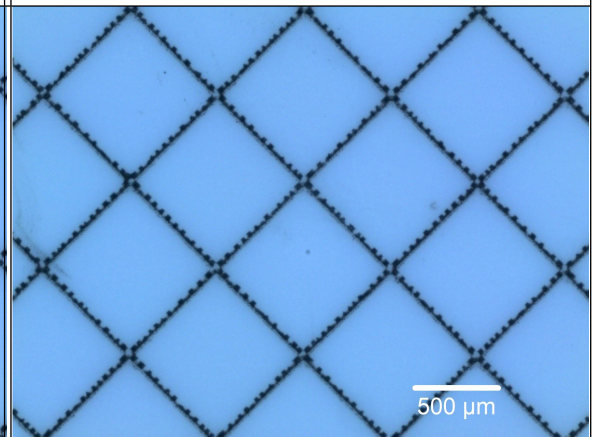
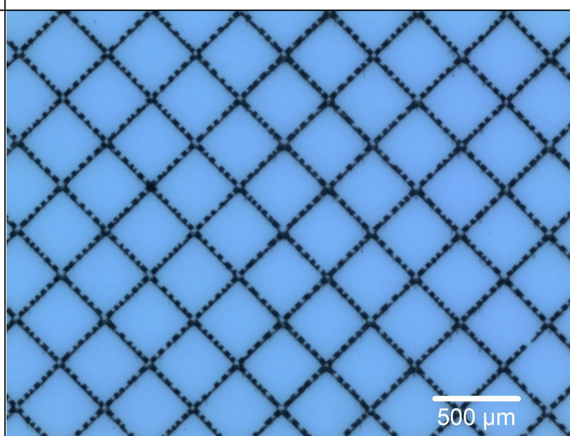
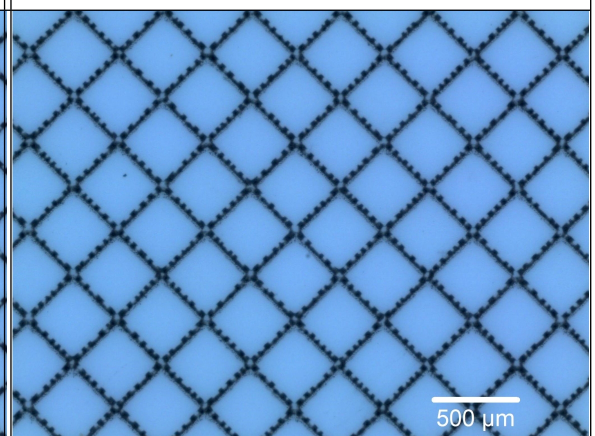
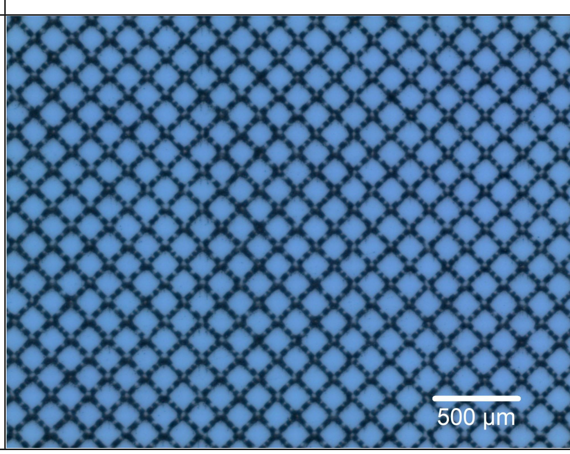
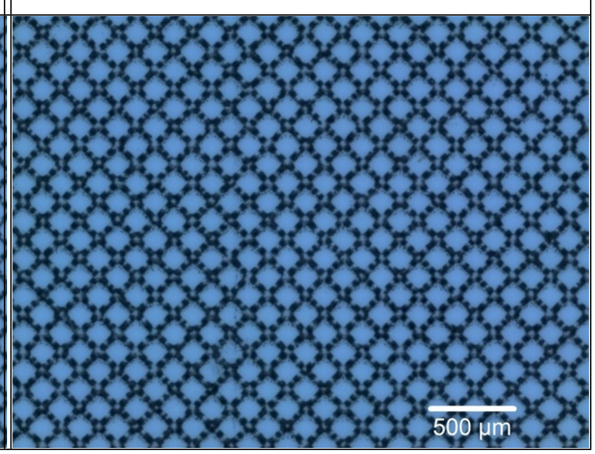
Grid Space (µm)	Trial Seven (T7) Print Experiment - 20 µm Grid (Blade Type: Plastic, Ink Type: ECI7007, Substrate Type: White PET)	
	chrome	Standard DLC
Space 1000 µm		
Space 500 µm		
Space 200 µm		

Figure S-29*. Trial Seven Print Experiment - 20 µm Grid (Blade Type: Plastic, Ink Type: ECI7007, Substrate Type: White PET).*

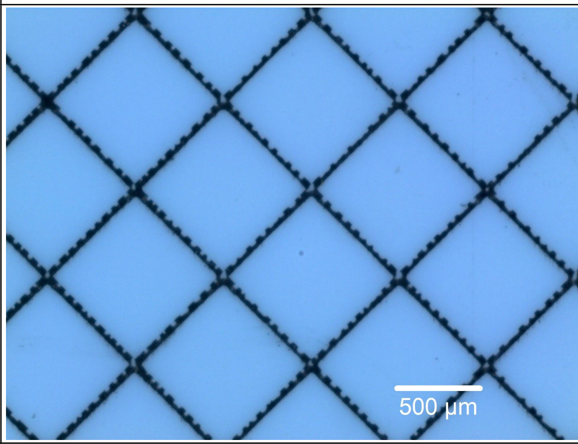
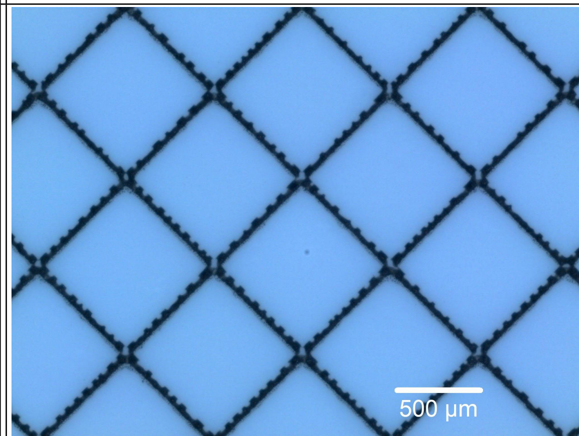
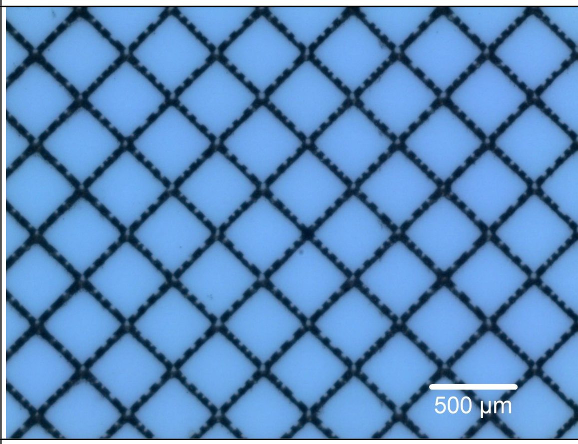
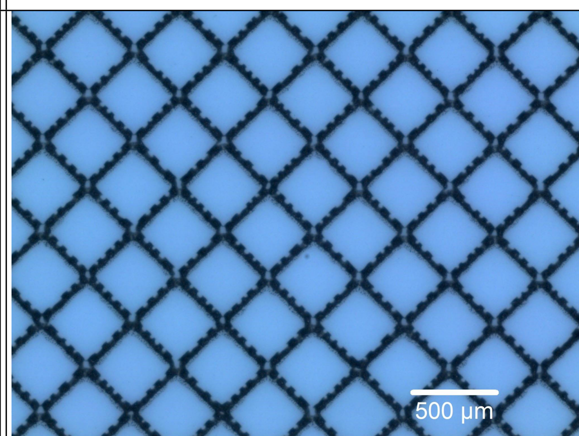
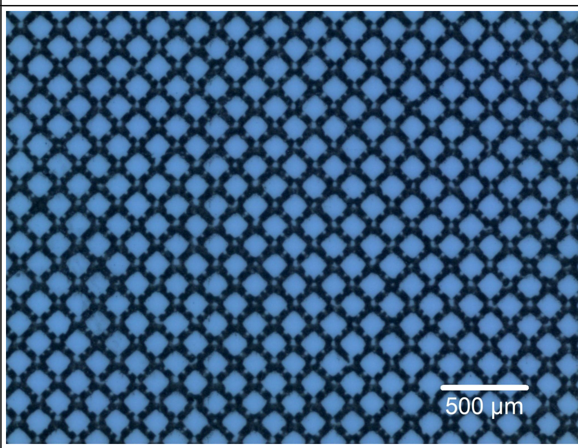
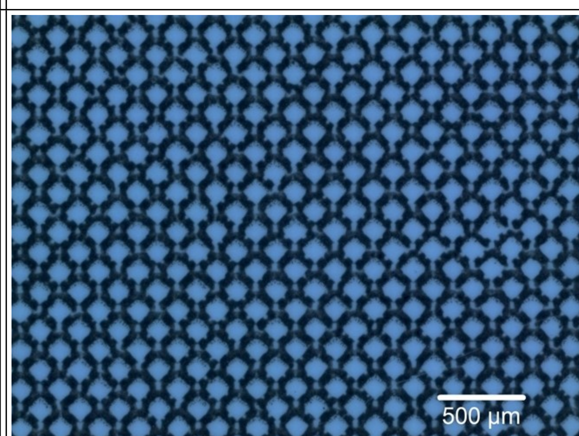
Grid Space (µm)	Trial Seven (T7) Print Experiment - 30 µm Grid (Blade Type: Plastic, Ink Type: ECI7007, Substrate Type: White PET)	
	chrome	Standard DLC
Space 1000 µm		
Space 500 µm		
Space 200 µm		

***Figure S-30**. Trial Seven Print Experiment - 30 µm Grid (Blade Type: Plastic, Ink Type: ECI7007, Substrate Type: White PET).*

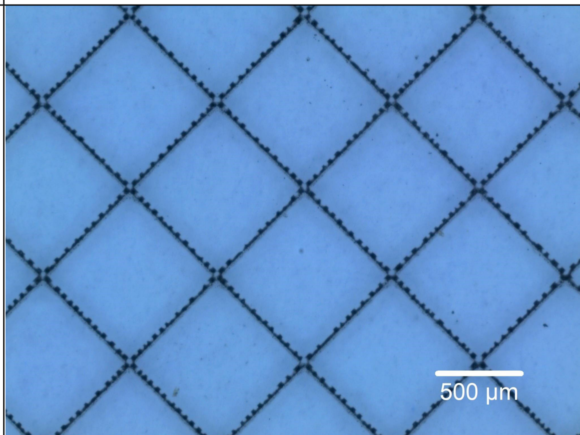
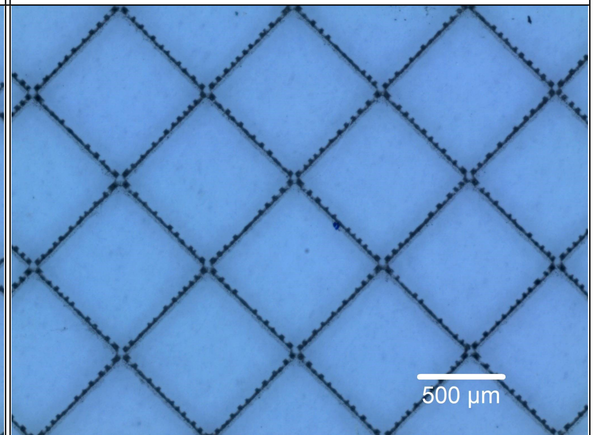
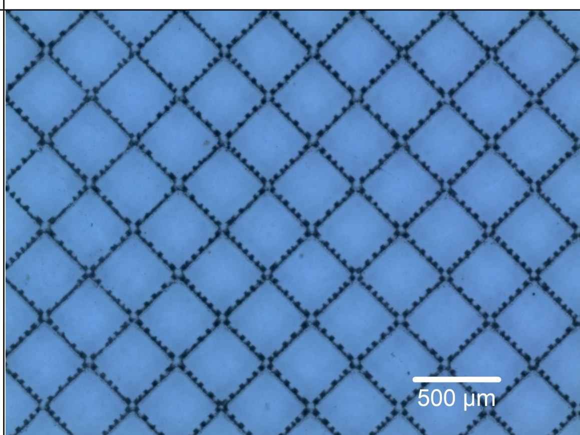
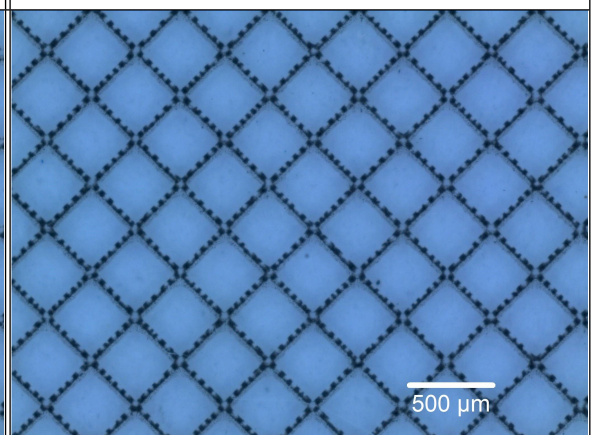
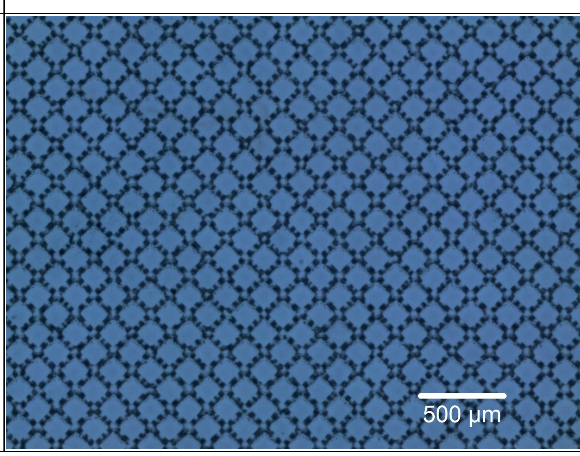
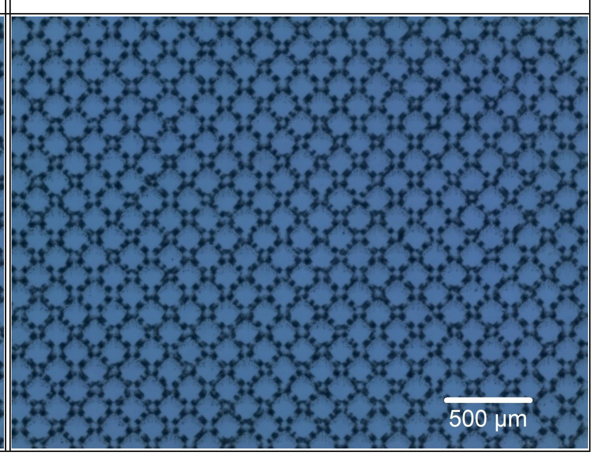
Grid Space (µm)	Trial Eight (T8) Print Experiment - 20 µm Grid (Blade Type: Plastic, Ink Type: ECI7007, Substrate Type: Clear PET)	
	chrome	Standard DLC
Space 1000 µm		
Space 500 µm		
Space 200 µm		

Figure S-31. *Trial Eight Print Experiment - 20 µm Grid (Blade Type: Plastic, Ink Type: ECI7007, Substrate Type: Clear PET)*

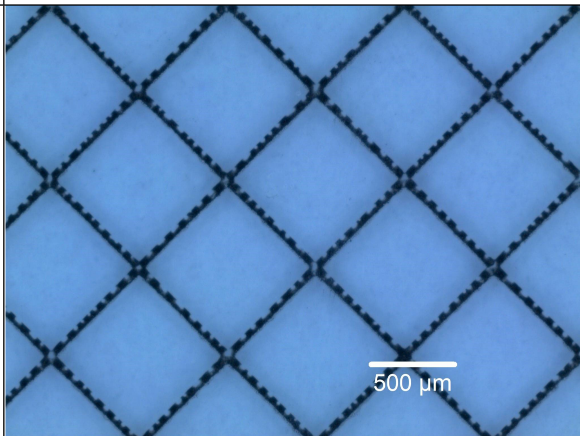
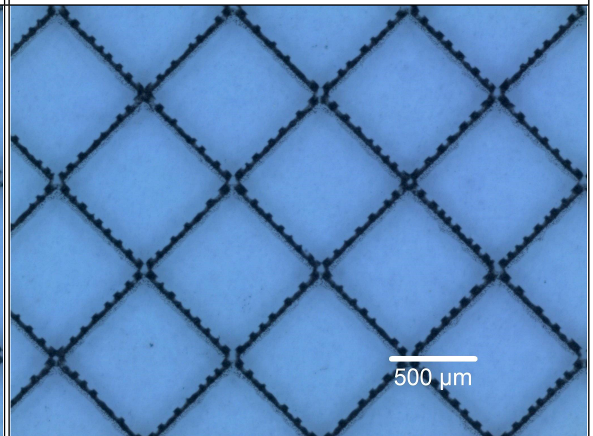
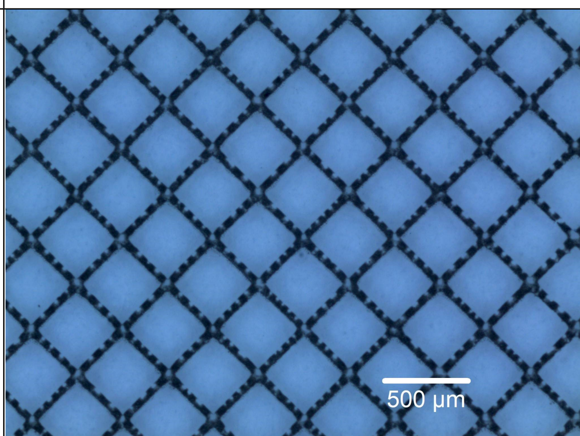
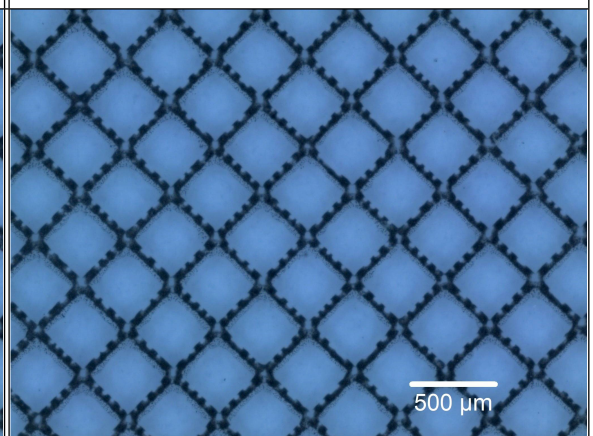
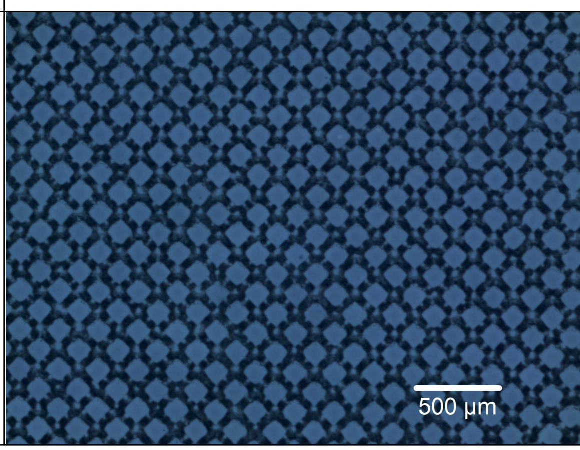
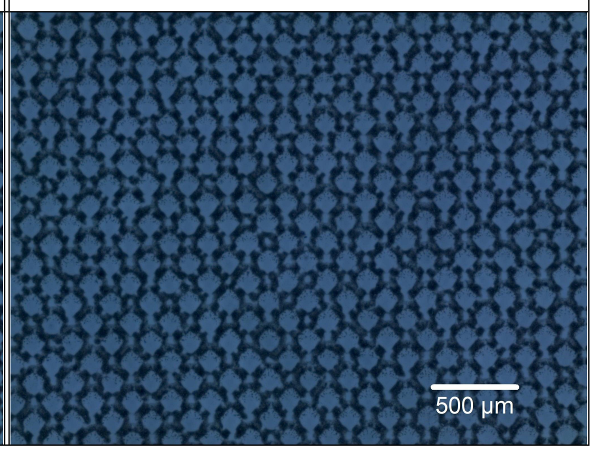
Grid Space (µm)	Trial Eight (T8) Print Experiment - 30 µm Grid (Blade Type: Plastic, Ink Type: ECI7007, Substrate Type: Clear PET)	
	chrome	Standard DLC
Space 1000 µm		
Space 500 µm		
Space 200 µm		

Figure S-32. *Trial Eight Print Experiment - 30 µm Grid (Blade Type: Plastic, Ink Type: ECI7007, Substrate Type: Clear PET)*

Statistical Analysis of Line Width

There were three print samples obtained for each of the trial experiments and associated print conditions. All of the three samples were used to collect 25 data point/replicates of line width data in one observation for each of the printed grids of 20 µm and 30 µm.

The statistical analysis of the line width data collected can be divided into two parts:

1. Comparing the DLC and chrome surfaces, using the same blade type, ink, and substrate for the eight trial experiments, for each individual line spacing under 20µm and 30µm grids, as well as for the combined grids spacing for the 20µm and 30µm line widths.

2. Performing a factorial analysis to identify which factors (surface, blade, substrate, ink, and grid) are significant to the line width.

Part 1 Results: –

Statistical analysis of data from eight experimental trials was conducted using Minitab software v21.2. A two-sample test for variance was applied to each comparison to determine whether to assume equal or unequal variance, followed by a two-sample t-test at a 5% significance level. The hypothesis that Standard DLC is better to chrome was tested. The results of the tests are tabulated in Tables S-1 and S-2. There were 25 observations for each grid spacing (1000 µm, 500 µm, and 200 µm) for 20 µm and 30 µm line widths, resulting in a total of 75 observations. In Table S-2, results are shown for 20 µm line widths.

Table S-2. *Statistical Comparisons of 20 µm Grids*

Trial No.	Surface Type	**20 µm Grid 2-sample t-test p value (<α=0.05: Reject Null hypothesis) ***							
		20 µm Grid 1000 µm Spacing (Samples size N = 25)		**20 µm Grid 500 µm Spacing (Samples size N = 25)**		**20 µm Grid 200 µm Spacing (Samples size N = 25)**		**20 µm Grid All Spacing (Samples Size in each Trial: N=75**	
		Avg Width ±*Std Dev*	P value	Avg Width ±*Std Dev*	P value	Avg Width ±*Std Dev*	P value	Avg Width ±*Std Dev*	P value
1	chrome	46.9 ±*1.3*	0.000	53.4 ±*0.6*	0.000	58.5 ±*1.1*	0.000	53.0 ±*4.9*	0.000
	Std DLC	51.4 ±*0.7*		57.2 ±*1.7*		59.9 ±*0.6*		56.2 ±*3.7*	
2	chrome	36.9 ±*1.3*	0.000	41.0 ±*0.6*	0.000	45.2 ±*0.5*	0.000	41.0 ±*3.6*	0.000
	Std DLC	41.7 ±*0.4*		44.9 ±*0.6*		51.7 ±*1.0*		46.1 ±*4.3*	
3	chrome	32.3 ±*1.0*	0.000	35.4 ±*1.4*	0.000	37.7 ±*1.8*	0.000	35.1 ±*2.7*	0.000
	Std DLC	36.3 ±*1.2*		39.4 ±*1.8*		40.3 ±*2.5*		38.7 ±*2.5*	
4	chrome	24.2 ±*2.0*	0.000	27.0 ±*1.2*	0.000	33.1 ±*2.2*	0.000	28.1 ±*4.2*	0.003
	Std DLC	26.7 ±*1.6*		28.6 ±*1.2*		34.4 ±*1.4*		29.9 ±*3.6*	
5	chrome	39.6 ±*0.7*	**0.868**	42.0 ±*0.3*	0.000	48.6 ±*0.3*	0.000	43.4 ±*3.9*	0.001
	Std DLC	39.4 ±*0.8*		45.0 ±*0.3*		53.9 ±*1.9*		46.1 ±*6.1*	
6	chrome	27.6 ±*2.1*	0.000	34.9 ±*0.5*	0.000	42.7 ±*2.3*	0.000	35.0 ±*6.5*	0.000
	Std DLC	31.7 ±*0.6*		38.1 ±*0.6*		50.7 ±*1.6*		40.1 ±*8.1*	

7	chrome	22.2 ±*0.8*	0.000	26.1 ±*0.5*	0.000	33.7 ±*1.1*	0.000	27.3 ±*4.9*	0.000
	Std DLC	26.4 ±*1.0*		33.2 ±*0.8*		39.7 ±*1.1*		33.1 ±*5.5*	
8	chrome	20.4 ±*1.0*	**0.333**	22.7 ±*1.0*	0.000	29.8 ±1.8	0.000	24.3 ±*4.2*	0.019
	Std DLC	20.5 ±*1.1*		24.6 ±*1.1*		32.5 ±*0.9*		25.9 ±*5.1*	

*Null Hypothesis: chrome(σ_1) >= (σ_2) DLC,
Alternate Hypothesis chrome (σ_1) < (σ_2) DLC,
Significance level: <α = 0.05

Note that for the 20 μm line widths, all conditions show a significant higher line width when using standard DLC surface than when using chrome surface except for two conditions. In these conditions, the p value is higher than 0.05 for 20 μm line width and 1000 μm spacing in trial T5 and T8 as shown. In Table S-3, results are shown for 30 μm line widths.

Table S-3. *Statistical Comparisons of 30 μm Grids*

Trial No.	**Surface Type**	**30 μm Grid 2-sample t-test p value (<α=0.05: Reject Null hypothesis)***							
		30 μm Grid 1000 μm Spacing (Samples size N = 25)		**30 μm Grid 500 μm Spacing (Samples size N = 25)**		**30 μm Grid 200 μm Spacing (Samples size N = 25)**		**30 μm Grid All Spacing (Samples Size in each Trial: N=75**	
		Avg Width ±*Std Dev*	P value	Avg Width ±*Std Dev*	P value	Avg Width ±*Std Dev*	P value	Avg Width ±*Std Dev*	P value
T1	chrome	67.1 ±*1.4*	0.000	71.3 ±*2.0*	0.000	85.2 ±*0.7*	0.000	74.5 ±*7.9*	0.000
	Std DLC	73.5 ±*1.5*		76.0 ±*1.2*		90.7 ±*1.2*		80.1 ±*7.8*	
T2	chrome	54.6 ±*2.7*	0.000	58.0 ±*1.0*	0.000	73.8 ±*2.3*	0.000	62.1 ±*8.7*	0.000
	Std DLC	62.1 ±*1.6*		64.6 ±*0.7*		82.9 ±*1.8*		69.9 ±*9.4*	
T3	chrome	46.2 ±*1.2*	0.000	47.5 ±*1.2*	0.000	53.7 ±*1.0*	0.000	49.2 ±*3.5*	0.000
	Std DLC	50.1 ±*1.8*		52.5 ±*1.7*		56.3 ±*1.9*		53.0 ±*3.1*	
T4	chrome	36.3 ±*2.1*	0.000	43.5 ±*1.9*	0.008	50.7 ±*2.2*	0.000	43.5 ±*6.3*	0.002
	Std DLC	40.7 ±*1.9*		44.8 ±*1.8*		53.8 ±*2.9*		46.4 ±*5.9*	
T5	chrome	58.7 ±*1.0*	0.023	59.9 ±0.7	0.000	72.4 ±*0.7*	0.000	63.7 ±*6.3*	0.001
	Std DLC	59.3 ±*1.3*		63.5 ±*0.6*		80.1 ±*0.6*		67.7 ±*9.1*	
T6	chrome	47.9 ±*1.3*	**0.406**	51.8 ±*1.0*	0.000	67.8 ±*0.8*	0.000	55.8 ±*8.7*	0.012
	Std DLC	48.0 ±*1.2*		56.1 ±*0.8*		74.6 ±*0.7*		59.6 ±*11.2*	
T7	chrome	38.2 ±*2.4*	0.000	40.7 ±*1.1*	0.000	49.5 ±*0.7*	0.000	42.8 ±*5.1*	0.000
	Std DLC	41.9 ±*1.5*		45.9 ±*1.1*		55.3 ±*0.9*		47.7 ±*5.8*	
T8	chrome	34.3 ±*1.2*	0.005	37.4 ±*0.7*	0.000	44.8 ±*1.2*	0.001	38.8 ±*4.5*	0.029
	Std DLC	35.6 ±*2.1*		39.2 ±*1.2*		46.0 ±*1.4*		40.3 ±*4.6*	

*Null Hypothesis: chrome(σ_1) >= (σ_2) DLC,
Alternate Hypothesis chrome (σ_1) < (σ_2) DLC,
Significance level: <α = 0.05

Note that for the 30 μm line widths, all conditions show a significant higher line width when using standard DLC surface than when using chrome surface except for one condition. In these conditions, the p value is higher than 0.05 for 30 μm line width and 1000 μm spacing in trial T6 as shown. Although the standard DLC surface still indicates a higher line width, the p value is greater than 0.05, indicating less than 95% confidence.

The two-sample t-test results of the grid-to-grid comparison indicate that the line width measured on printed samples of standard DLC is higher than that of chrome, and is statistically significant with a p-value less than 0.005 in all cases, except for a few where the line width of the print samples obtained from both the standard DLC and chrome were the same. Moreover, the t-test results of all grids comparison were found to be statistically significant.

Part 2 Results: –

a. Residual plots –

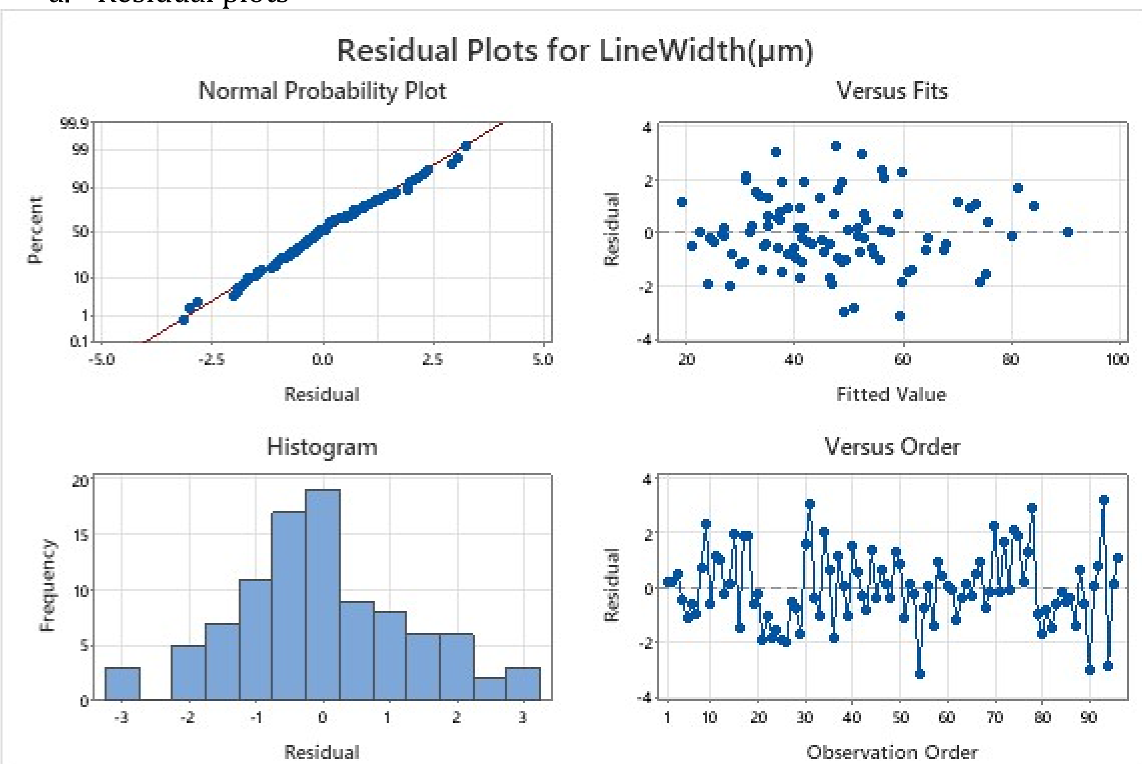


Figure S-33. *Residual plots for Line Width from Minitab. Results suggest acceptable normality, equity of variance and randomness of data.*

The residual plot helps to assess whether all the assumptions of ANOVA are met.

i. Normality: The normal probability plot and histogram suggest that normality is acceptable.
ii. Equality of variance: The versus fit plot shows some clustering between the 40 and 60 μm areas, but the variance appears to be equal.
iii. Independence and randomness: The versus order plot doesn't have any discernible pattern, showing acceptable randomness, independence of data, and minimal bias.

Conclusion – ANOVA appears to be valid.

b. Minitab output for the ANOVA –

Table S-4. *Analysis of variance in Minitab*

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Surface	1	382.9	382.87	140.29	0.000
Blade	1	1257.1	1257.07	460.59	0.000
Substrate	1	1454.4	1454.38	532.89	0.000
Ink	1	7923.9	7923.92	2903.33	0.000
Grid	5	10858.6	2171.72	795.72	0.000
Surface*Blade	1	2.0	2.03	0.74	0.392
Surface*Substrate	1	2.0	2.00	0.73	0.396
Surface*Ink	1	12.3	12.27	4.50	0.038
Surface*Grid	5	11.6	2.33	0.85	0.519
Blade*Substrate	1	44.1	44.05	16.14	0.000
Blade*Ink	1	70.1	70.12	25.69	0.000
Blade*Grid	5	66.3	13.26	4.86	0.001
Substrate*Ink	1	64.1	64.08	23.48	0.000
Substrate*Grid	5	32.2	6.45	2.36	0.051
Ink*Grid	5	477.2	95.44	34.97	0.000
Error	60	163.8	2.73		
Total	95	22822.5			

The ANOVA results in Table S-4, indicate that the surface, blade, substrate, ink and grid factors all have a significant impact on line width, as the p-value is less than 0.005 for these factors. Additionally, the surface does have some impact on ink with respect to line width as shown in this p value. However, the surface does not have an impact on blade, ink or grid, as expected. There is significant interaction between the blade and the substrate, the ink, and the grid. This would indicate that the blade type effect and the effect on line width from the substrate, the ink, and the grid are interrelated. This is to be expected as the blade interaction with the blade is likely dependent on the chemical composition and properties (i.e. viscosity, mixing) of the ink likely affect interaction with the blade leading this this interaction in dependence. There is significant interaction between dependence of line width with substrate and ink with near-significant interrelation of dependence between the substrate and grid. This is to be expected as the ink interacts with the substrate differently based on the composition of the ink and the substrate, while the substrate can have some impact on the grid due to the substrate surface properties and chemical composition. Finally, the line width dependence on ink and grid are interrelated as the ink must have a relationship with grid. This is to be expected as the inks have much different viscosity, thereby affecting the grid line width that can be printed.