

# What Is the Current State of Sustainability in the Decorative Electroplating Industry? A Close Look at New Practices and Advances

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## S1. Materials and Methods

Commercial brass plates from Ossian Lagerqvist AB (Jarfalla, Sweden) were used as substrate: 0.250 mm thickness, 50.0 mm length, 37.5 mm width. The plates were drilled in the center of the short side, at the apical position, the hole has a diameter of 5 mm. The brass surface was electroplated with a thick layer of nickel (>20  $\mu\text{m}$ ).

The thickness distribution study was carried out in an area of 24.35 cm x 31.6 cm, 16 plates were placed in each electroplating rack.

The commercial nickel electroplating solution used presented the following characteristics: nickel (II) sulfate 230 g/L, Nickel (II) chloride 50 g/L, boric acid 48 g/L, brightening additive 11 mL/L, carrier additive 40 mL/L, pH (25 °C) 4.5. The operating conditions specified by the supplier are: working temperature 55 °C and cathodic current 5 A/dm<sup>2</sup>.

The electroplating solution "Bluclad 8693" presents the following characteristics: Au 2.5 g/L, Fe 0.5 g/L, pH (25 °C) 4. The operating conditions specified by the supplier are: working temperature 40 °C, cathodic current 2 A/dm<sup>2</sup>. The study was carried out for deposits that present a thickness of about 0.5  $\mu\text{m}$ .

All the X-Ray Fluorescence measurements were performed using a Bowman (Schaumburg, IL, USA) BA-100 P series. The thicknesses of each plate were evaluated by XRF analysis on 5 points for each plate: one at the center and four points at all the corners.

The formulation "Bluclad 8614 MUP" presents the following characteristics: Au 1.1 g/L, Ni 1.6 g/L, In 0.09 g/L, pH (25 °C) 4. The operating conditions were working temperature 36 °C, cathodic current 1 A/dm<sup>2</sup>. The depositions performed using this formulation were carried out with a duration of 10 minutes. In the case of pulsed current depositions, a pulse current of 2 A/dm<sup>2</sup> was used, with a pulse and pause time equal to 33 ms, maintaining the average current density at 1 A/dm<sup>2</sup>. The rectifier used in this case is a commercial rectifier supplied by the company R.C.V. Srl (Altavilla Vicentina, VI, Italy).

**Table S1.** Data on the position on the galvanic frame and the thicknesses of electrodeposited gold relative to the sample obtained under standard conditions, using the Anti-Peak Effect Rectifier (RAEP) system and using the Homogeneous Coating System (HCS).

Standard conditions			RAEP			HCS		
X-axis position (cm)	Y-axis position (cm)	Deposit Thickness ( $\mu\text{m}$ )	X-axis position (cm)	Y-axis position (cm)	Deposit Thickness ( $\mu\text{m}$ )	X-axis position (cm)	Y-axis position (cm)	Deposit Thickness ( $\mu\text{m}$ )
0.00	0.00	0.85	0.00	0.00	0.48	0.00	0.00	0.49
3.35	0.00	0.55	3.35	0.00	0.63	3.35	0.00	0.58
1.68	2.30	0.42	1.68	2.30	0.37	1.68	2.30	0.28
0.00	4.60	0.75	0.00	4.60	0.55	0.00	4.60	0.65
3.35	4.60	0.64	3.35	4.60	0.56	3.35	4.60	0.56
7.00	0.00	0.65	7.00	0.00	0.48	7.00	0.00	0.51
10.35	0.00	0.73	10.35	0.00	0.56	10.35	0.00	0.58
8.68	2.30	0.39	8.68	2.30	0.38	8.68	2.30	0.28
7.00	4.60	0.74	7.00	4.60	0.59	7.00	4.60	0.60
10.35	4.60	0.78	10.35	4.60	0.58	10.35	4.60	0.63
14.00	0.00	0.65	14.00	0.00	0.50	14.00	0.00	0.56
17.35	0.00	0.81	17.35	0.00	0.53	17.35	0.00	0.48
15.68	2.30	0.39	15.68	2.30	0.42	15.68	2.30	0.31
14.00	4.60	0.63	14.00	4.60	0.59	14.00	4.60	0.58
17.35	4.60	0.61	17.35	4.60	0.63	17.35	4.60	0.63
21.00	0.00	0.58	21.00	0.00	0.54	21.00	0.00	0.51
24.35	0.00	0.68	24.35	0.00	0.50	24.35	0.00	0.61
22.68	2.30	0.38	22.68	2.30	0.39	22.68	2.30	0.28
21.00	4.60	0.71	21.00	4.60	0.54	21.00	4.60	0.60
24.35	4.60	0.64	24.35	4.60	0.54	24.35	4.60	0.70
0.00	9.00	0.91	0.00	9.00	0.52	0.00	9.00	0.49
3.35	9.00	0.51	3.35	9.00	0.61	3.35	9.00	0.63
1.68	11.30	0.40	1.68	11.30	0.37	1.68	11.30	0.29
0.00	13.60	0.63	0.00	13.60	0.59	0.00	13.60	0.45
3.35	13.60	0.62	3.35	13.60	0.50	3.35	13.60	0.52
7.00	9.00	0.60	7.00	9.00	0.53	7.00	9.00	0.55
10.35	9.00	0.62	10.35	9.00	0.60	10.35	9.00	0.67
8.68	11.30	0.34	8.68	11.30	0.29	8.68	11.30	0.29
7.00	13.60	0.56	7.00	13.60	0.54	7.00	13.60	0.56
10.35	13.60	0.54	10.35	13.60	0.60	10.35	13.60	0.60
14.00	9.00	0.68	14.00	9.00	0.63	14.00	9.00	0.60
17.35	9.00	0.53	17.35	9.00	0.54	17.35	9.00	0.53
15.68	11.30	0.38	15.68	11.30	0.36	15.68	11.30	0.33
14.00	13.60	0.62	14.00	13.60	0.57	14.00	13.60	0.68
17.35	13.60	0.57	17.35	13.60	0.58	17.35	13.60	0.51
21.00	9.00	0.71	21.00	9.00	0.63	21.00	9.00	0.64
24.35	9.00	0.44	24.35	9.00	0.56	24.35	9.00	0.46
22.68	11.30	0.34	22.68	11.30	0.35	22.68	11.30	0.27
21.00	13.60	0.55	21.00	13.60	0.59	21.00	13.60	0.66

24.35	13.60	0.69	24.35	13.60	0.54	24.35	13.60	0.66
0.00	18.00	0.58	0.00	18.00	0.64	0.00	18.00	0.59
3.35	18.00	0.61	3.35	18.00	0.53	3.35	18.00	0.73
1.68	20.30	0.39	1.68	20.30	0.34	1.68	20.30	0.27
0.00	22.60	0.70	0.00	22.60	0.54	0.00	22.60	0.56
3.35	22.60	0.71	3.35	22.60	0.49	3.35	22.60	0.54
7.00	18.00	0.54	7.00	18.00	0.53	7.00	18.00	0.50
10.35	18.00	0.47	10.35	18.00	0.56	10.35	18.00	0.56
8.68	20.30	0.30	8.68	20.30	0.34	8.68	20.30	0.29
7.00	22.60	0.48	7.00	22.60	0.53	7.00	22.60	0.58
10.35	22.60	0.58	10.35	22.60	0.49	10.35	22.60	0.66
14.00	18.00	0.57	14.00	18.00	0.59	14.00	18.00	0.60
17.35	18.00	0.61	17.35	18.00	0.53	17.35	18.00	0.60
15.68	20.30	0.35	15.68	20.30	0.36	15.68	20.30	0.30
14.00	22.60	0.56	14.00	22.60	0.55	14.00	22.60	0.64
17.35	22.60	0.50	17.35	22.60	0.53	17.35	22.60	0.57
21.00	18.00	0.73	21.00	18.00	0.64	21.00	18.00	0.63
24.35	18.00	0.57	24.35	18.00	0.57	24.35	18.00	0.46
22.68	20.30	0.41	22.68	20.30	0.32	22.68	20.30	0.29
21.00	22.60	0.67	21.00	22.60	0.48	21.00	22.60	0.54
24.35	22.60	0.50	24.35	22.60	0.53	24.35	22.60	0.80
0.00	27.00	0.78	0.00	27.00	0.58	0.00	27.00	0.64
3.35	27.00	0.56	3.35	27.00	0.57	3.35	27.00	0.53
1.68	29.30	0.31	1.68	29.30	0.36	1.68	29.30	0.30
0.00	31.60	0.63	0.00	31.60	0.53	0.00	31.60	0.51
3.35	31.60	0.56	3.35	31.60	0.57	3.35	31.60	0.52
7.00	27.00	0.46	7.00	27.00	0.56	7.00	27.00	0.71
10.35	27.00	0.64	10.35	27.00	0.52	10.35	27.00	0.55
8.68	29.30	0.33	8.68	29.30	0.35	8.68	29.30	0.30
7.00	31.60	0.53	7.00	31.60	0.67	7.00	31.60	0.56
10.35	31.60	0.51	10.35	31.60	0.57	10.35	31.60	0.61
14.00	27.00	0.55	14.00	27.00	0.48	14.00	27.00	0.62
17.35	27.00	0.52	17.35	27.00	0.51	17.35	27.00	0.51
15.68	29.30	0.38	15.68	29.30	0.33	15.68	29.30	0.32
14.00	31.60	0.60	14.00	31.60	0.59	14.00	31.60	0.69
17.35	31.60	0.55	17.35	31.60	0.57	17.35	31.60	0.62
21.00	27.00	0.55	21.00	27.00	0.48	21.00	27.00	0.71
24.35	27.00	0.80	24.35	27.00	0.57	24.35	27.00	0.55
22.68	29.30	0.35	22.68	29.30	0.34	22.68	29.30	0.30
21.00	31.60	0.59	21.00	31.60	0.61	21.00	31.60	0.59
24.35	31.60	0.55	24.35	31.60	0.73	24.35	31.60	0.64

**Table S2.** Data on the position on the galvanic frame and the thicknesses of electrodeposited gold relative to the sample obtained under direct current conditions and under pulsed current conditions.

Direct current			Pulsed current		
X-axis position (cm)	Y-axis position (cm)	Deposit Thickness ( $\mu\text{m}$ )	X-axis position (cm)	Y-axis position (cm)	Deposit Thickness ( $\mu\text{m}$ )
0.00	0.00	0.72	0.00	0.00	0.58
3.35	0.00	0.65	3.35	0.00	0.97
1.68	2.30	0.23	1.68	2.30	0.41
0.00	4.60	0.30	0.00	4.60	0.69
3.35	4.60	0.56	3.35	4.60	0.83
7.00	0.00	0.46	7.00	0.00	0.59
10.35	0.00	0.78	10.35	0.00	0.73
8.68	2.30	0.33	8.68	2.30	0.45
7.00	4.60	0.38	7.00	4.60	0.46
10.35	4.60	0.49	10.35	4.60	0.72
14.00	0.00	0.80	14.00	0.00	0.71
17.35	0.00	0.57	17.35	0.00	0.75
15.68	2.30	0.31	15.68	2.30	0.58
14.00	4.60	0.68	14.00	4.60	1.02
17.35	4.60	0.48	17.35	4.60	0.93
21.00	0.00	0.41	21.00	0.00	0.71
24.35	0.00	0.46	24.35	0.00	0.83
22.68	2.30	0.36	22.68	2.30	0.45
21.00	4.60	0.41	21.00	4.60	0.61
24.35	4.60	0.48	24.35	4.60	0.93
0.00	9.00	0.72	0.00	9.00	1.01
3.35	9.00	0.70	3.35	9.00	0.84
1.68	11.30	0.25	1.68	11.30	0.40
0.00	13.60	0.34	0.00	13.60	0.72
3.35	13.60	0.32	3.35	13.60	0.77
7.00	9.00	0.50	7.00	9.00	0.58
10.35	9.00	0.48	10.35	9.00	0.63
8.68	11.30	0.27	8.68	11.30	0.43
7.00	13.60	0.33	7.00	13.60	0.49
10.35	13.60	0.43	10.35	13.60	0.68
14.00	9.00	0.57	14.00	9.00	0.69
17.35	9.00	0.57	17.35	9.00	0.79
15.68	11.30	0.28	15.68	11.30	0.43
14.00	13.60	0.42	14.00	13.60	0.80
17.35	13.60	0.54	17.35	13.60	0.87
21.00	9.00	0.58	21.00	9.00	0.87
24.35	9.00	0.51	24.35	9.00	0.88
22.68	11.30	0.38	22.68	11.30	0.48
21.00	13.60	0.71	21.00	13.60	0.68
24.35	13.60	0.54	24.35	13.60	0.86
0.00	18.00	0.59	0.00	18.00	0.74

3.35	18.00	0.63	3.35	18.00	0.81
1.68	20.30	0.29	1.68	20.30	0.36
0.00	22.60	0.42	0.00	22.60	0.60
3.35	22.60	0.32	3.35	22.60	0.62
7.00	18.00	0.52	7.00	18.00	0.72
10.35	18.00	0.52	10.35	18.00	0.78
8.68	20.30	0.21	8.68	20.30	0.40
7.00	22.60	0.40	7.00	22.60	0.63
10.35	22.60	0.31	10.35	22.60	0.59
14.00	18.00	0.55	14.00	18.00	0.62
17.35	18.00	0.46	17.35	18.00	0.72
15.68	20.30	0.31	15.68	20.30	0.45
14.00	22.60	0.66	14.00	22.60	0.68
17.35	22.60	0.57	17.35	22.60	0.76
21.00	18.00	0.48	21.00	18.00	0.83
24.35	18.00	0.43	24.35	18.00	0.85
22.68	20.30	0.44	22.68	20.30	0.48
21.00	22.60	0.48	21.00	22.60	0.88
24.35	22.60	0.57	24.35	22.60	0.91
0.00	27.00	0.58	0.00	27.00	0.77
3.35	27.00	0.67	3.35	27.00	0.73
1.68	29.30	0.22	1.68	29.30	0.33
0.00	31.60	0.45	0.00	31.60	0.53
3.35	31.60	0.23	3.35	31.60	0.41
7.00	27.00	0.51	7.00	27.00	0.82
10.35	27.00	0.48	10.35	27.00	0.70
8.68	29.30	0.26	8.68	29.30	0.35
7.00	31.60	0.39	7.00	31.60	0.65
10.35	31.60	0.38	10.35	31.60	0.42
14.00	27.00	0.63	14.00	27.00	0.56
17.35	27.00	0.68	17.35	27.00	0.79
15.68	29.30	0.53	15.68	29.30	0.50
14.00	31.60	0.95	14.00	31.60	0.62
17.35	31.60	0.74	17.35	31.60	0.88
21.00	27.00	0.55	21.00	27.00	0.92
24.35	27.00	0.55	24.35	27.00	0.85
22.68	29.30	0.43	22.68	29.30	0.52
21.00	31.60	0.65	21.00	31.60	0.91
24.35	31.60	0.62	24.35	31.60	0.93

Table S3. Sample results after NSS test ISO 9227 for 48 h.

Standard DC1		RAEP		HCS		Standard DC2		Pulsed current	
Sample	Result	Sample	Result	Sample	Result	Sample	Result	Sample	Result
DCFE1	4	RAEP1	5	HCS1	3	DC1V	1	PC1	1
DCFE2	4	RAEP2	4	HCS2	3	DC2V	2	PC2	4
DCFE3	4	RAEP3	5	HCS3	3	DC3V	2	PC3	3
DCFE4	5	RAEP4	4	HCS4	3	DC4V	1	PC4	3
Average	4.3	Average	4.5	Average	3	Average	1.5	Average	2.8

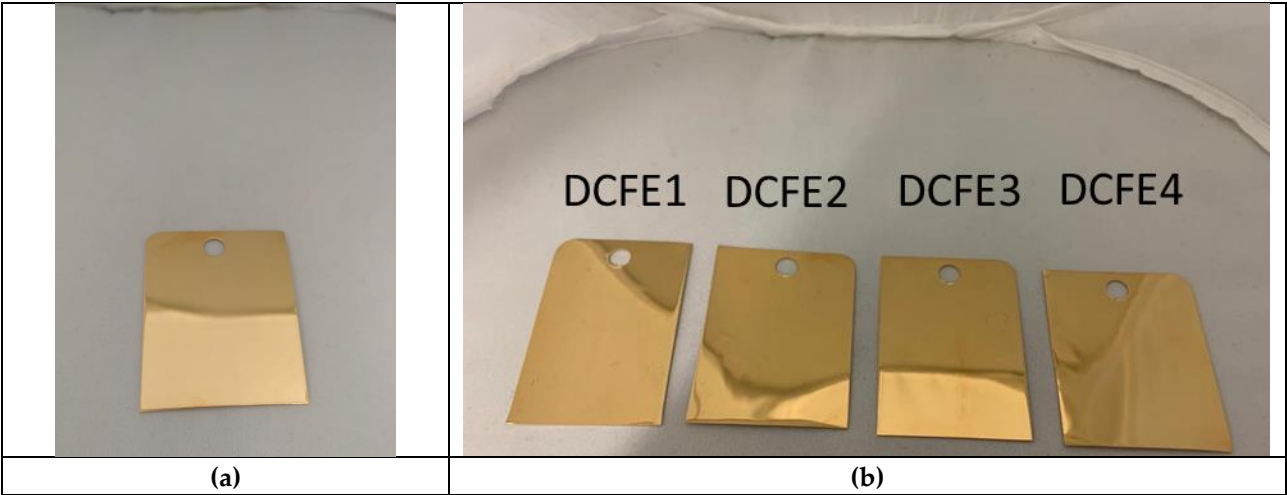


Figure S1. Samples obtained under standard conditions using "Bluclad 8693" electroplating solution; a) image obtained before corrosion test, b) image obtained after corrosion test.

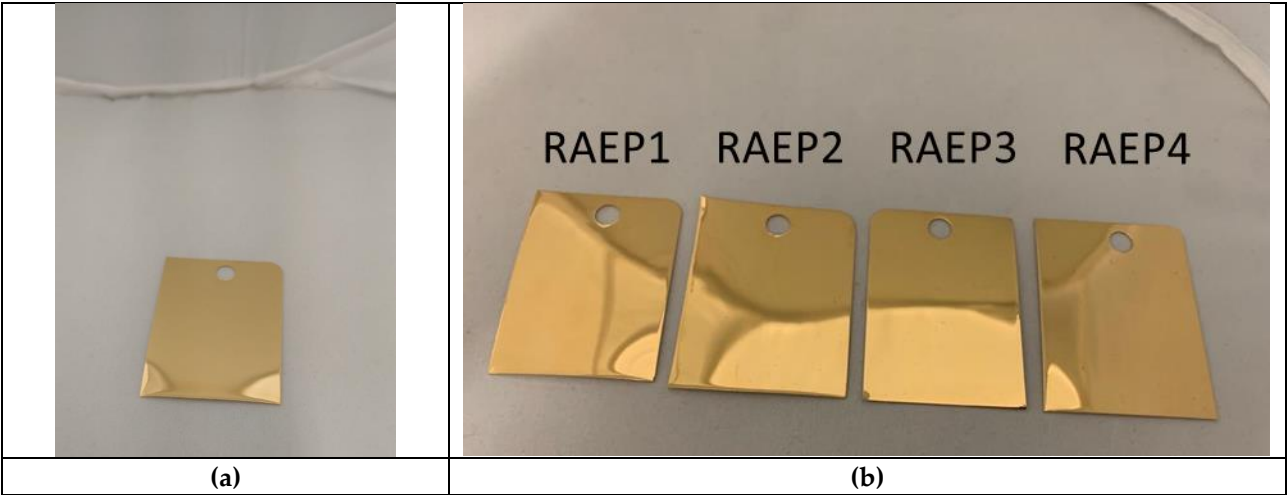
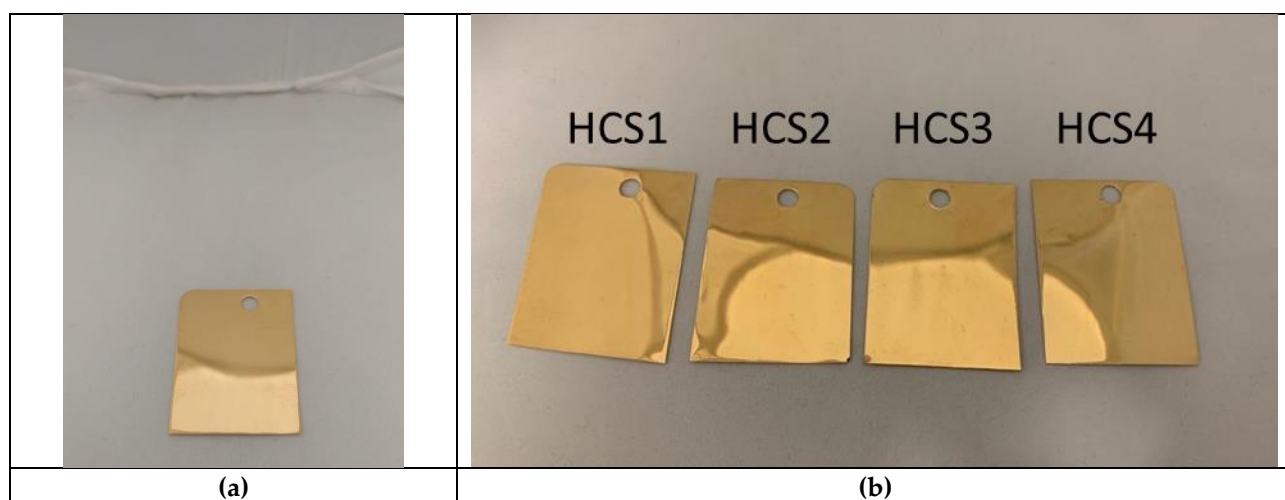
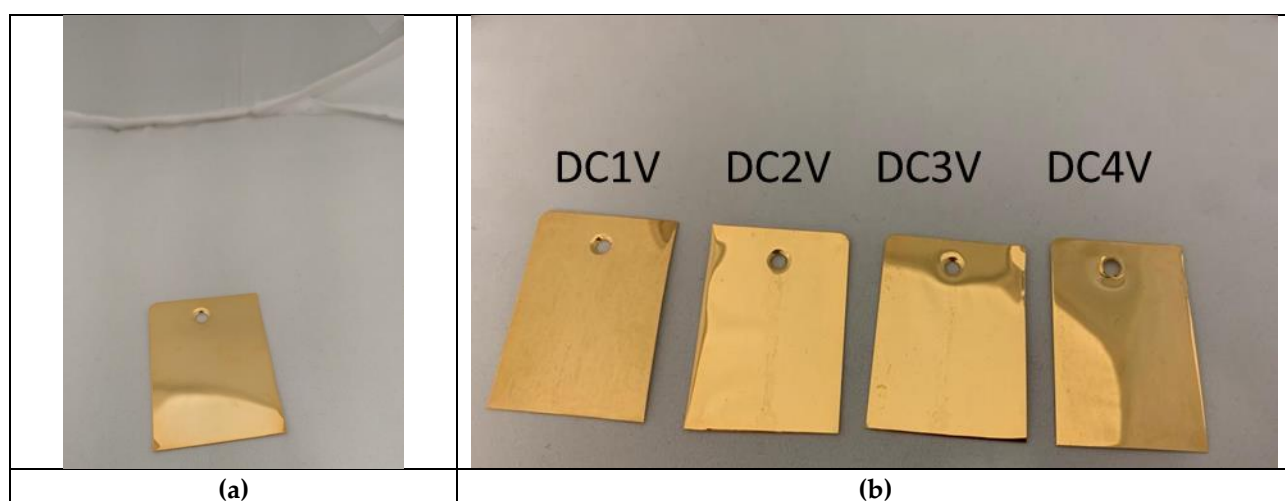


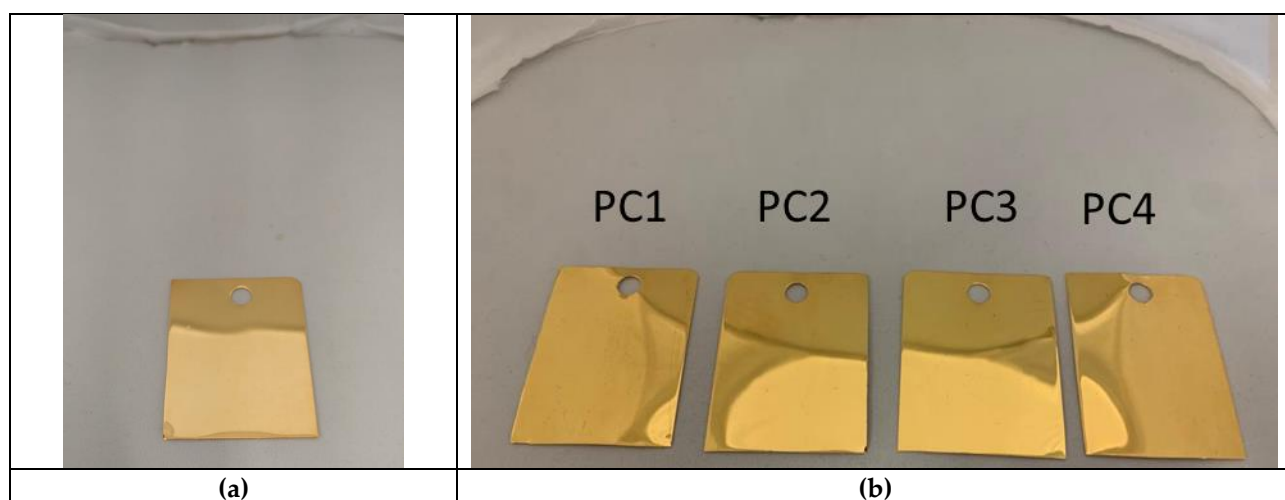
Figure S2. Samples obtained using the Anti-Peak Effect Rectifier (RAEP) system using "Bluclad 8693" electroplating solution; a) image obtained before corrosion test, b) image obtained after corrosion test.



**Figure S3.** Samples obtained using the Homogeneous Coating System (HCS) system using "Bluclad 8693" electroplating solution; a) image obtained before corrosion test, b) image obtained after corrosion test.



**Figure S4.** Samples obtained under standard conditions using "Bluclad 8614 MUP" electroplating solution; a) image obtained before corrosion test, b) image obtained after corrosion test.



**Figure S5.** Sample obtained under Pulsed Current deposition conditions using "Bluclad 8614 MUP" electroplating solution; a) image obtained before corrosion test, b) image obtained after corrosion test.