

## **Electronic Supplementary Information:**

### **Inkjet-printed Ag electrodes on paper for high sensitivity impedance measurements**

Hanbin Ma<sup>a</sup>, Yang Su<sup>a</sup>, Chen Jiang<sup>a</sup> and Arokia Nathan<sup>a\*</sup>

<sup>a</sup>Department of Engineering, Electrical Engineering Division, University of Cambridge

\* To whom correspondence should be addressed:

Tel: +44 (0) 1223 748302

Fax: +44 (0) 1223 748322

E-mail: an299@cam.ac.uk

**ESI Table 1. Concentrations of NaCl solution used for measurements and their electrical properties**

NaCl solution concentration (mg/ml)	Approx. conductivity (S/m)	Approx. relative permittivity
0.312	0.0617	80.2
0.625	0.1240	80.1
1.25	0.2480	79.8

**ESI Table 2. Model extracted parameters for the impedance measurements**

	Electrode	NaCl concentrations (mg/ml)		
		0.312	0.625	1.25
Solution resistance $R_s$ ( $\Omega$ )	Au	4378	2256	1150
	Non-passivated Ag	3895	2194	1208
	Passivated Ag	4185	2348	1260
Solution capacitance $C_s$ (F)	Au	8.25e-12	8.11e-12	7.69e-12
	Nano-passivated Ag	1.28e-11	1.25e-11	1.17e-11
	Passivated Ag	1.35e-11	1.33e-11	1.26e-11

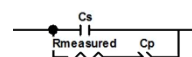
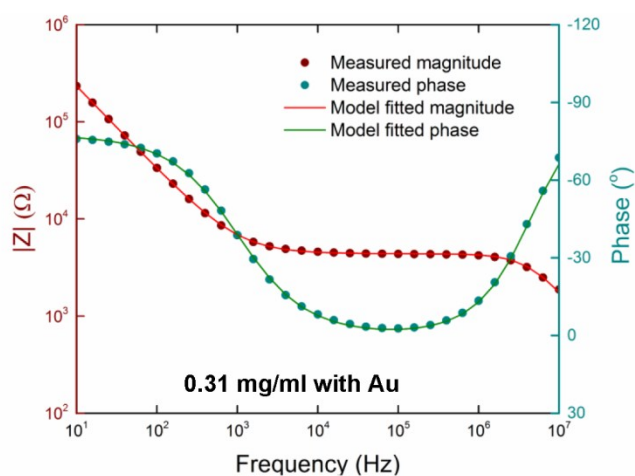
### **ESI: Office inkjet printer and commercial ink**

In this work, an office inkjet printer (Brother MFC-J6510DW) was used. The circuit printer cartridge set which is compatible with Brother printer was directly purchased from AgIC Inc. The cartridges containing AgIC #1000 inks were designed for short-term use prototyping use. It can be printed on glossy paper directly without the need for a sintering process. The printed sheet thickness is around 135  $\mu\text{m}$  and sheet resistance is 0.3  $\Omega/\text{Sq}$ . (<https://agic.cc/en#index-inks>)

### **ESI: Wetting issue between paper and printed Ag electrode**

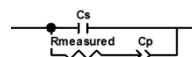
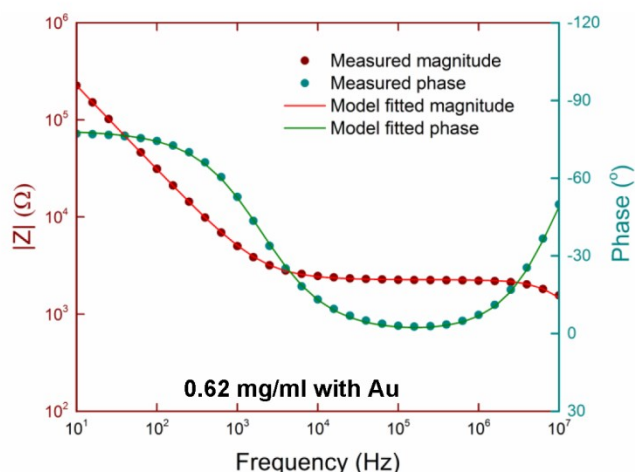
The silver ink cartridge used in this work was purchased from industrial supplier (AgIC), which can be printed on glossy paper directly. Wetting issue between paper and conductive ink has been solved by the supplier. In addition, for impedance measurement, only the conductive electrode, electrode-electrolyte interface and the sample solution are involved in the measurement circuit loop. The effects from insulated paper substrate and the interface between paper and electrodes are negligible, and therefore are not mentioned and discussed in the main article.

ESI Figure 1. Model fitting results for gold electrodes with equivalent circuit as shown in Fig. 3.b



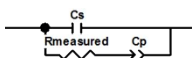
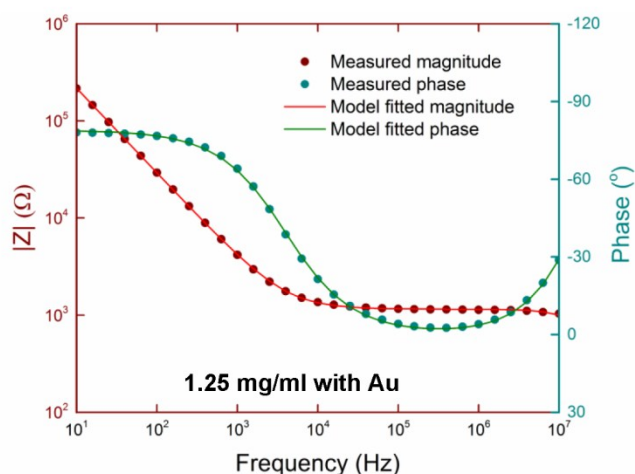
Element	Freedom	Value	Error	Error %
Cs	Free( $\pm$ )	8.2497E-12	7.1486E-14	0.86653
Rmeasured	Free( $\pm$ )	4378	14.752	0.33696
Cp-T	Free( $\pm$ )	1.214E-07	1.64E-09	1.3509
Cp-P	Free( $\pm$ )	0.86056	0.0020223	0.235

Chi-Squared: 0.00090231  
 Weighted Sum of Squares: 0.052334



Element	Freedom	Value	Error	Error %
Cs	Free( $\pm$ )	8.1073E-12	8.765E-14	1.0811
Rmeasured	Free( $\pm$ )	2256	6.7521	0.2993
Cp-T	Free( $\pm$ )	1.2034E-07	1.3322E-09	1.107
Cp-P	Free( $\pm$ )	0.87002	0.0015757	0.18111

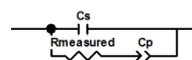
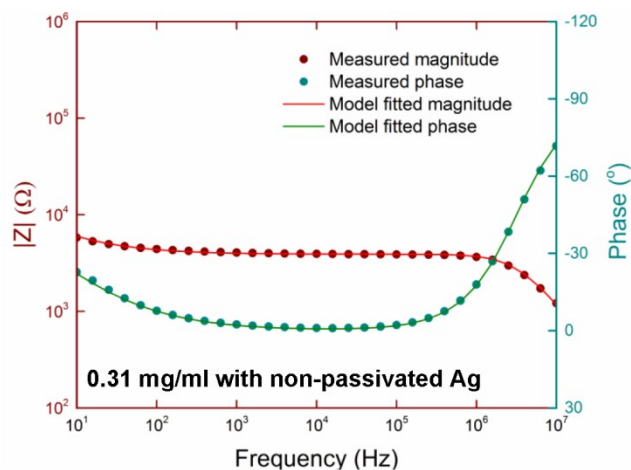
Chi-Squared: 0.00074712  
 Weighted Sum of Squares: 0.043333



Element	Freedom	Value	Error	Error %
Cs	Free( $\pm$ )	7.6947E-12	1.1544E-13	1.5003
Rmeasured	Free( $\pm$ )	1150	2.851	0.24791
Cp-T	Free( $\pm$ )	1.2133E-07	1.0201E-09	0.84076
Cp-P	Free( $\pm$ )	0.87714	0.001139	0.12985

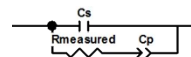
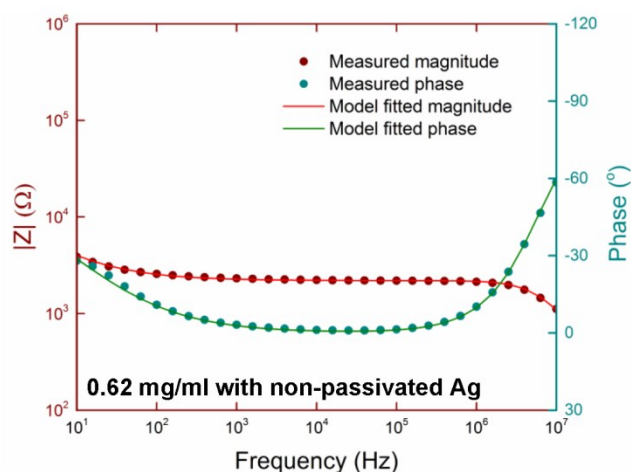
Chi-Squared: 0.00053491  
 Weighted Sum of Squares: 0.031025

**ESI Figure 2. Model fitting results for non-passivated Ag electrodes with equivalent circuit as shown in Fig. 3.b**



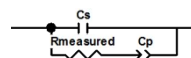
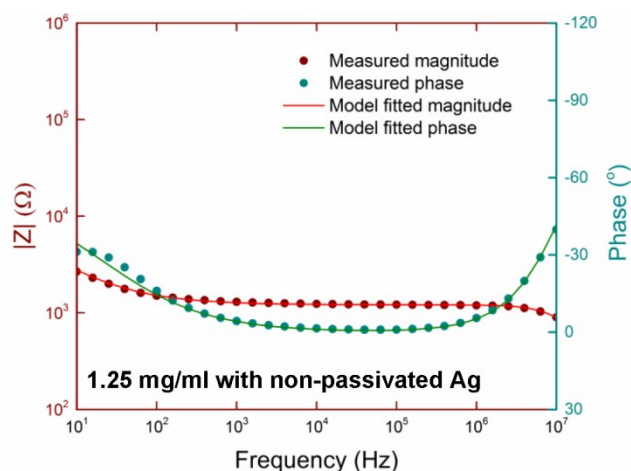
Element	Freedom	Value	Error	Error %
Cs	Free(±)	1.2882E-11	8.9008E-14	0.69095
Rmeasured	Free(±)	3895	11.405	0.29281
Cp-T	Free(±)	3.0207E-05	1.4228E-06	4.7102
Cp-P	Free(±)	0.5961	0.0094817	1.5906

Chi-Squared: 0.00183  
Weighted Sum of Squares: 0.10614



Element	Freedom	Value	Error	Error %
Cs	Free(±)	1.2508E-11	1.2742E-13	1.0187
Rmeasured	Free(±)	2194	7.1582	0.32626
Cp-T	Free(±)	3.3107E-05	1.3983E-06	4.2236
Cp-P	Free(±)	0.61841	0.0083277	1.3466

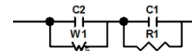
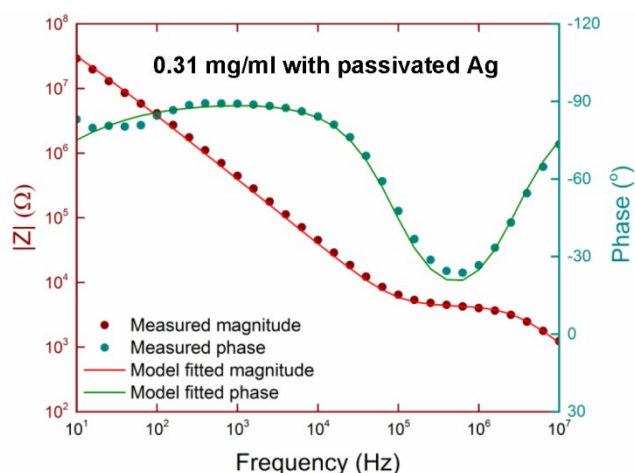
Chi-Squared: 0.0024738  
Weighted Sum of Squares: 0.14348



Element	Freedom	Value	Error	Error %
Cs	Free(±)	1.1678E-11	2.293E-13	1.9635
Rmeasured	Free(±)	1208	5.0748	0.4201
Cp-T	Free(±)	4.0995E-05	1.8106E-06	4.4166
Cp-P	Free(±)	0.61613	0.0084383	1.3696

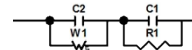
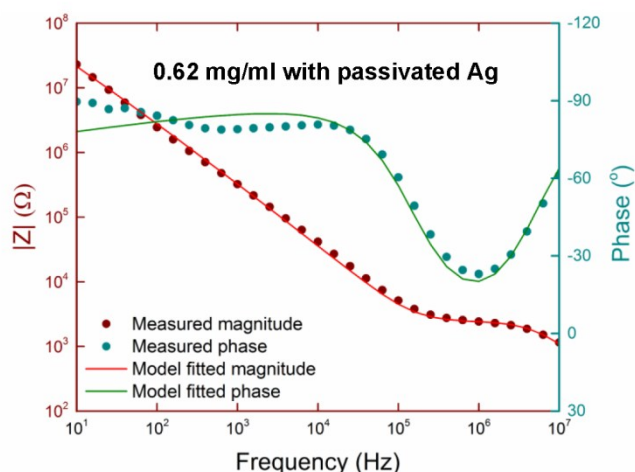
Chi-Squared: 0.004238  
Weighted Sum of Squares: 0.2458

ESI Figure 3. Model fitting results for passivated Ag electrodes with equivalent circuit as shown in Fig. 3.e



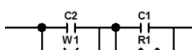
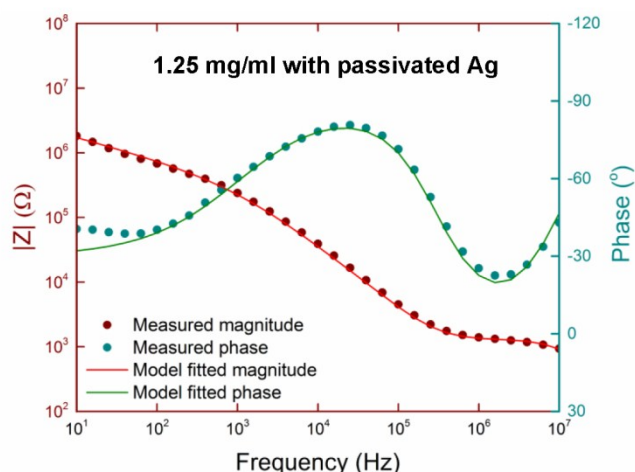
Element	Freedom	Value	Error	Error %
C2	Fixed(X)	4E-10	N/A	N/A
W1-R	Free(±)	3.2033E08	1.9515E09	609.22
W1-T	Free(+)	0.34828	5.3905	1547.7
W1-P	Free(+)	0.37336	0.0293214	24.966
C1	Free(+)	1.3527E-11	5.8393E-13	4.3168
R1	Free(+)	4185	122.87	2.936

Chi-Squared: 0.039118  
Weighted Sum of Squares: 2.2298



Element	Freedom	Value	Error	Error %
C2	Fixed(X)	4E-10	N/A	N/A
W1-R	Free(±)	3.9701E08	5.0804E09	1279.7
W1-T	Free(+)	0.33704	5.9692	1771.1
W1-P	Free(+)	0.71907	0.029371	4.0846
C1	Free(+)	1.3323E-11	8.5434E-13	6.4125
R1	Free(+)	2348	82.521	3.5145

Chi-Squared: 0.04198  
Weighted Sum of Squares: 2.3928



Element	Freedom	Value	Error	Error %
C2	Fixed(X)	4E-10	N/A	N/A
W1-R	Free(±)	2.7412E07	1.05E13	3.8304E07
W1-T	Free(+)	60.98	7.0137E07	1.1502E08
W1-P	Free(+)	0.33305	0.0087123	2.6159
C1	Free(+)	1.2563E-11	7.8859E-13	6.2771
R1	Free(+)	1260	30.31	2.4056

Chi-Squared: 0.010438  
Weighted Sum of Squares: 0.59497