Bubble printing of liquid metal colloidal particles for conductive patterns

Masaru Mukai[1], Tatsuya Kobayashi[2], Mitsuki Sato[2], Juri Asada[2], Kazuhide Ueno[1], Taichi Furukawa[1] and Shoji Maruo[1]*

1. Faculty of Engineering, Yokohama National University, 79-5 Tokiwadai, Hodogaya-ku, Yokohama 240-8501, Japan
2. Graduate School of Engineering Science, Yokohama National University, 79-5 Tokiwadai, Hodogaya-ku, Yokohama 240-8501, Japan

(*Electronic mail: maruo-shoji-rk@ynu.ac.jp)

Table S1. Comparison of this study to previous studies on bubble printing using conductive materials.

	Edri (2021) et al.	**Edri (2020) et al.**	**Nishiyama (2019) et al**	**Roy (2013) et al.**	**Armon (2021) et al.**	**This work**
Representative conductivity	3.1×10^5 S/m (Calculated)	3.8 x 10 S/m (Calculated, HCl dope)	Not described	Not described	1.0×10^6 S/m (Calculated, Sintering with HCl)	1.5×10^5 S/m
Scan speed	100 μm/s	200 ~ 800 μm/s	40 ～ 900 μm/s	>1 mm/s	10 μm/s ~ 9 mm/s	800 μm/s
Maximum Resolution （width)	≅ 4 μm	650 nm	2.0 μm	≅ 4 μm	1.7 μm	3.4 μm
Method	Bubble printing + thermochemical reaction	Bubble printing	Bublle printing + Photochemical reaction	Bubble printing	Bubble printing	Bubble printing
Dispersant	$PtCl_2$	Conductive polymer (polyaniline)	$AgNO_3$ + (TiO_2,SiO_2, Fe_2O_3)	Carbon nanotube (CNT) +Soft oxometalate (SOM)	Ag particles	Ga-In (Galvanic replacement)
Laser souce	532 nm (CW)	532 nm (CW)	780 nm (Femtosecond laser)	1064 nm (CW)	532 nm (CW)	752 nm (Femtosecond laser)
Dispersion medium	NMP	NMP	EtOH + H_2O	H_2O	Diethylene glycol butyl ether	NMP
Reference No. (DOI:)	[27] (https://doi.org/10.1021/acsami.1c06204)	[24] (https://doi.org/10.1021/acsami.0c00904)	[26] (https://doi.org/10.1038/s41598-019-50630-1)	[25] (https://doi.org/10.1021/la402777e)	[13] (https://doi.org/10.1021/acsami.7b14614)	-

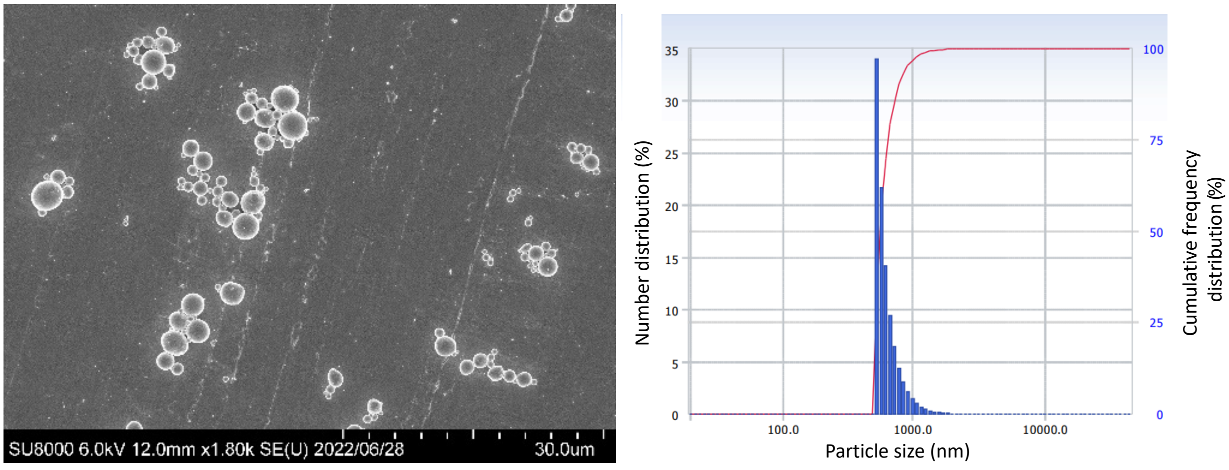

Figure S1. Scanning electron microscope (SEM) image and dynamic light scattering (DLS) histogram of gallium-indium eutectic alloys (Ga-In) particles.

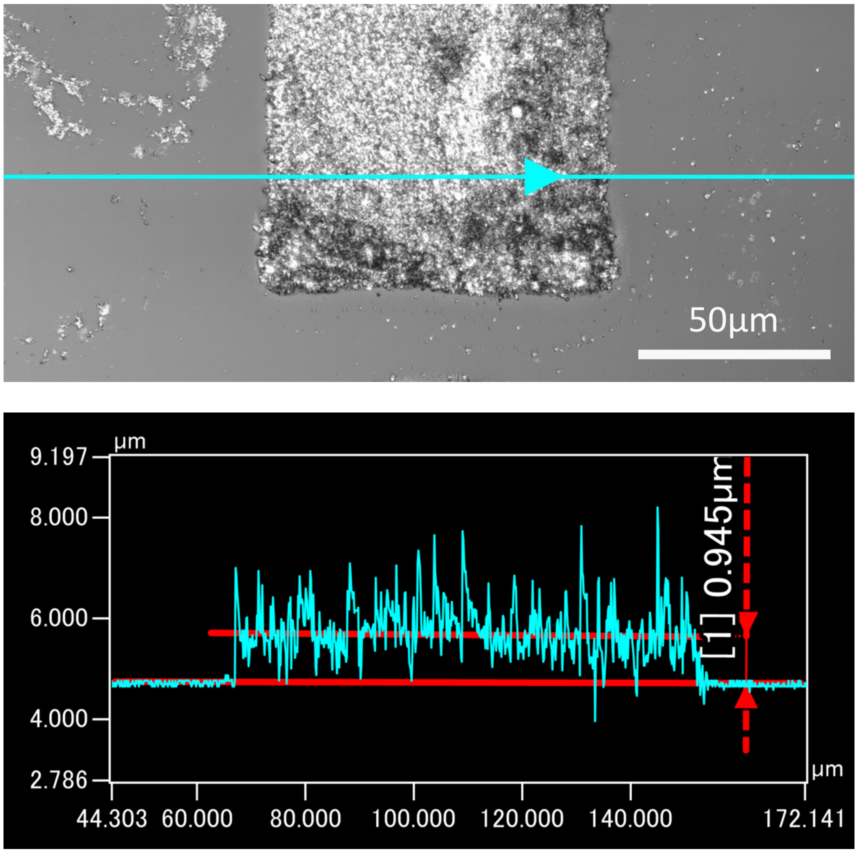

Figure S2. Example of height evaluation of the fabricated line using a laser scanning microscope.

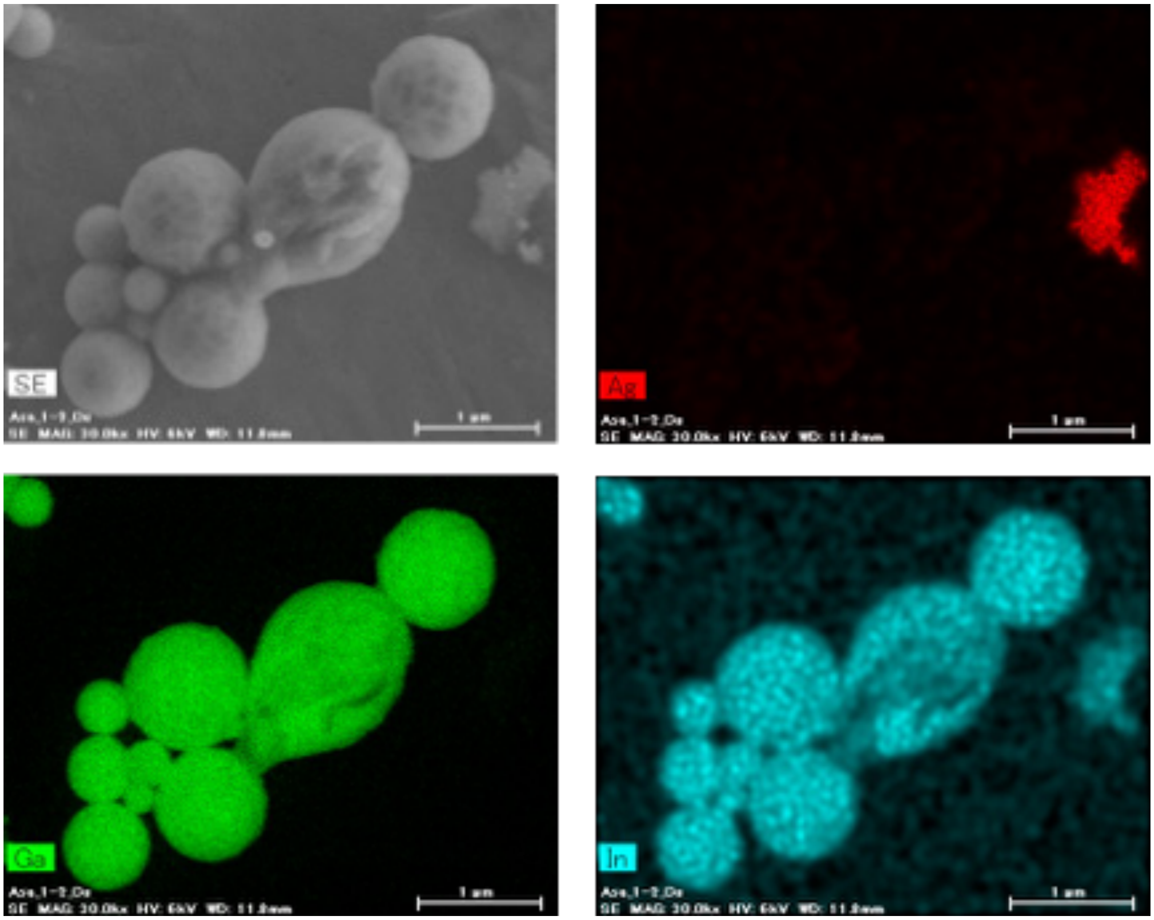

Figure S3. Energy Dispersive X-ray Spectroscopy (EDX) -SEM image of a sample in which silver nitrate ($AgNO_3$) was added in NMP to attempt galvanic replacement of the surface of Ga-In colloidal particles. EDX mapping of Silver (Ag) on Ga-In colloidal particles has not been observed, and experiments using Ga-In colloidal particles in *N*-methylpyrrolidone (NMP) confirm the difficulty of galvanic replacement of the colloidal particles. Acceleration voltage: 6 kV.

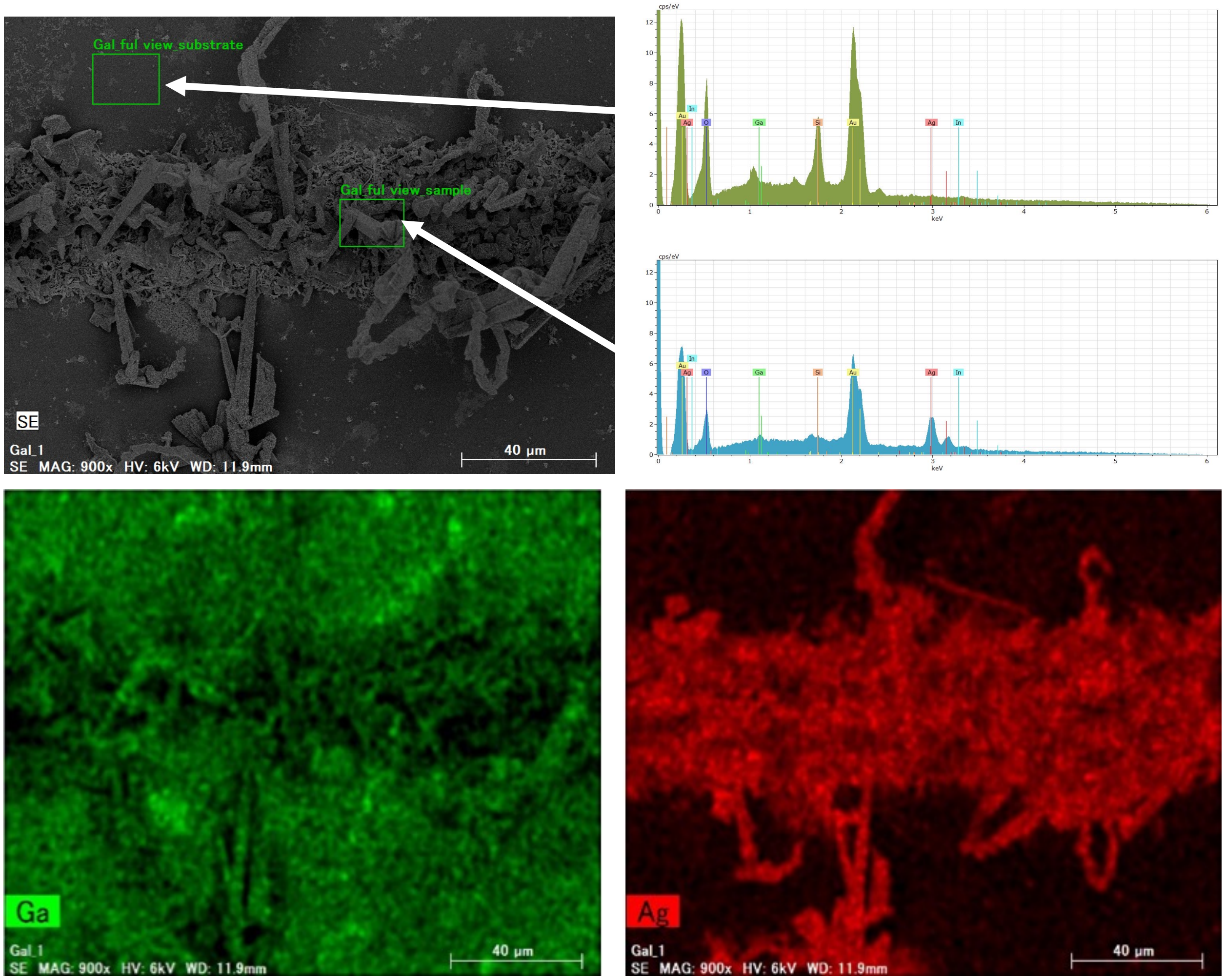

Figure S4. EDX spectra of the inside and outside of the processed line for galvanic replacement with 0.5 M $AgNO_3$ for 24 h and the corresponding EDX mapping of gallium (Ga), and Ag. Acceleration voltage: 6 kV.

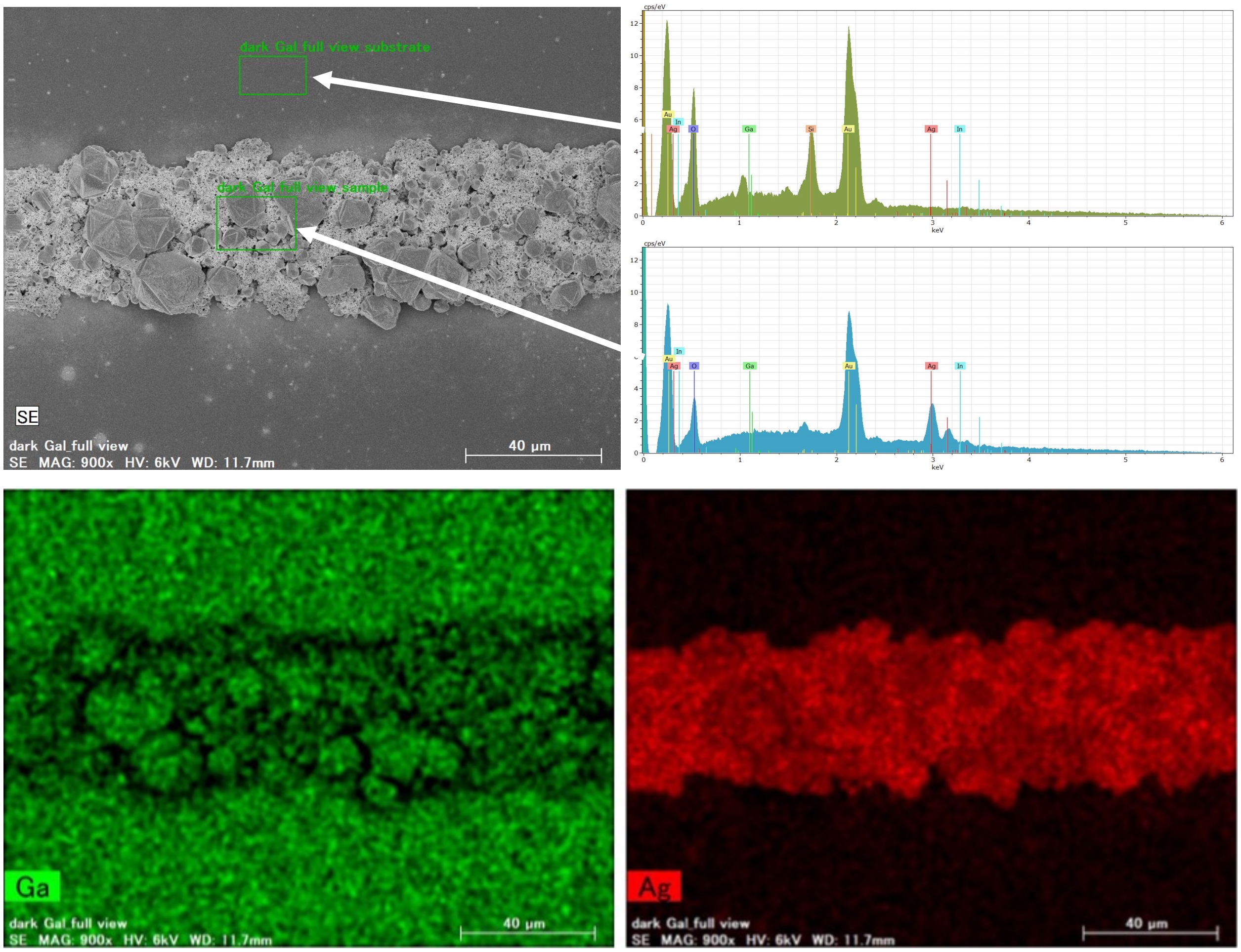

Figure S5. EDX spectra of the inside and outside of the processed line for galvanic replacement with 12.7 M $AgNO_3$ for 24 h and the corresponding EDX mapping of Ga, and Ag. Acceleration voltage: 6 kV.

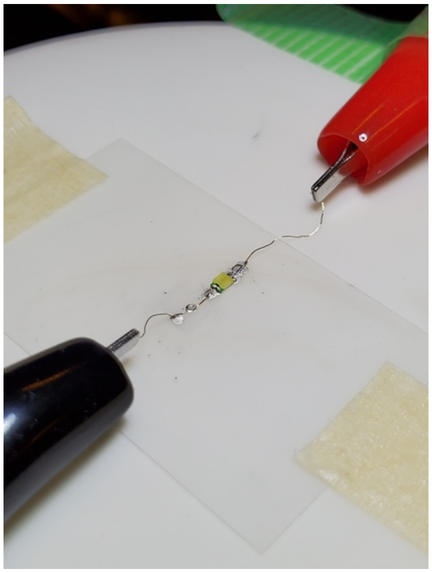

Figure S6. Off state of the fabricated wiring and SMD LED.

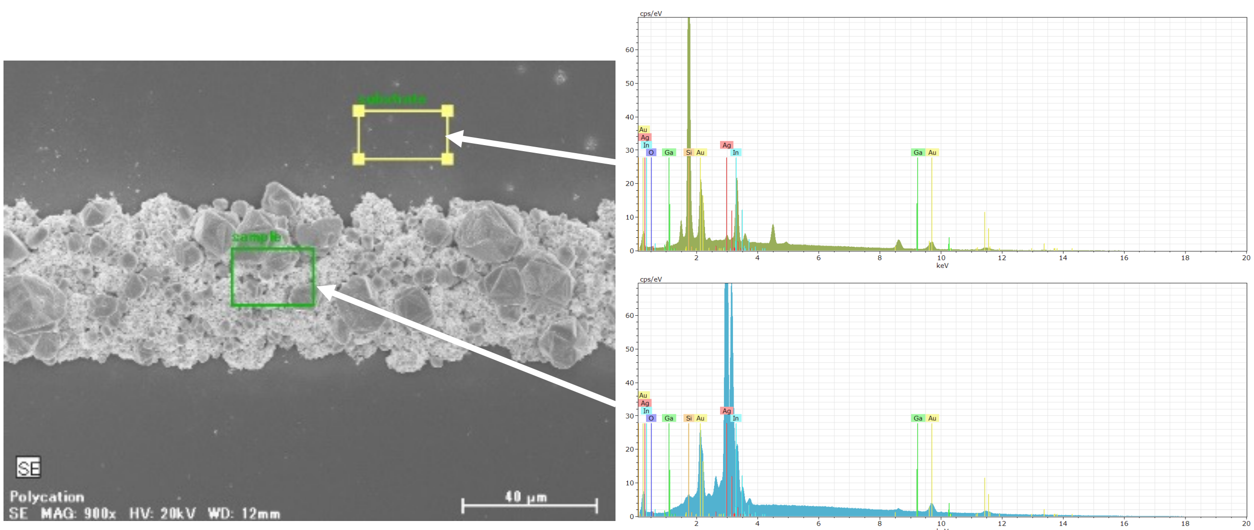

Figure S7. EDX spectra of the inside and outside of the processed line for galvanic replacement with 12.7 M $AgNO_3$ for 24 h and the corresponding EDX mapping of Ga, and Ag. Acceleration voltage: 20 kV.

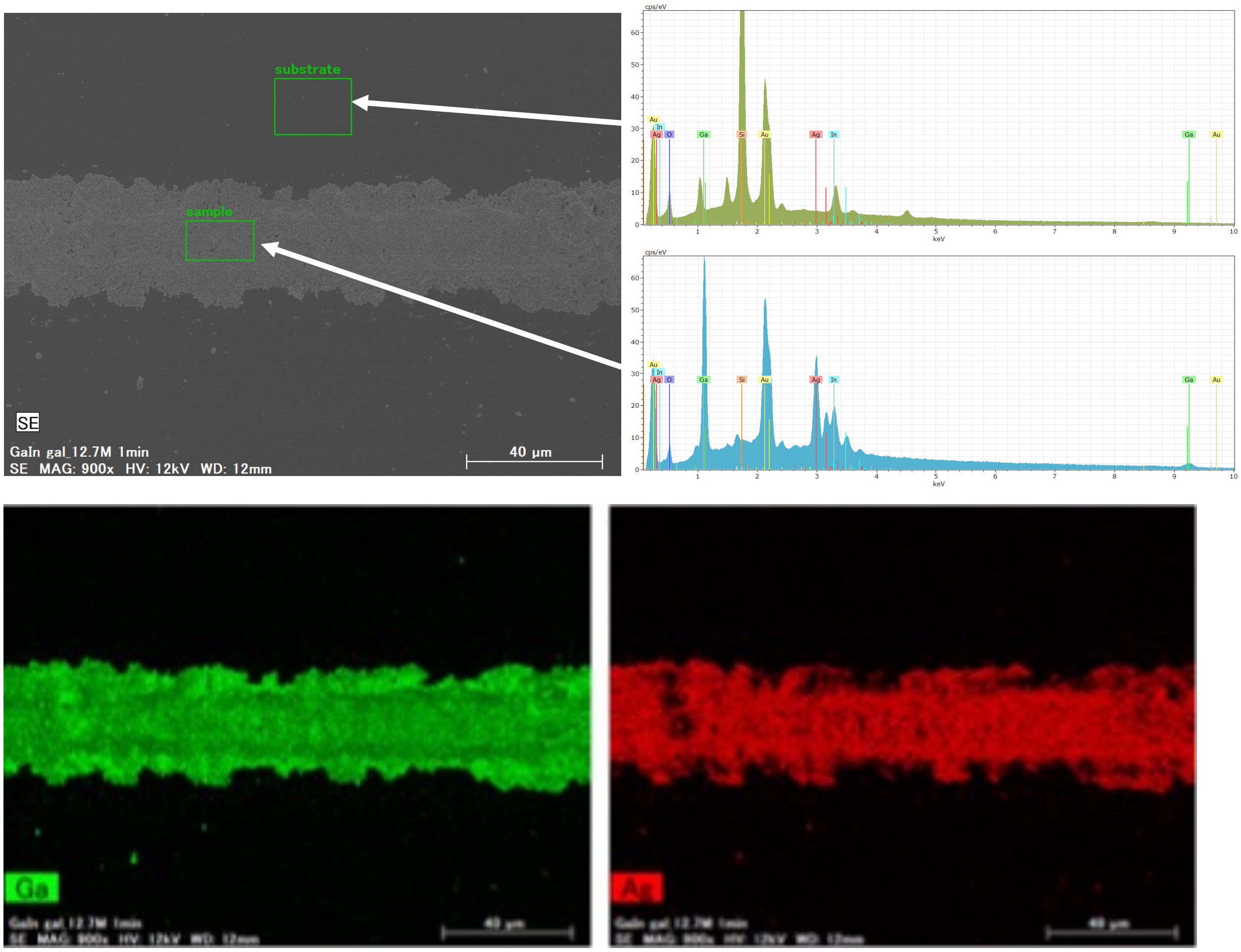

Figure S8. EDX spectra of the inside and outside of the processed line for galvanic replacement with 12.7 M $AgNO_3$ for 1 min and the corresponding EDX mapping of Ga, and Ag. Acceleration voltage: 6 kV.

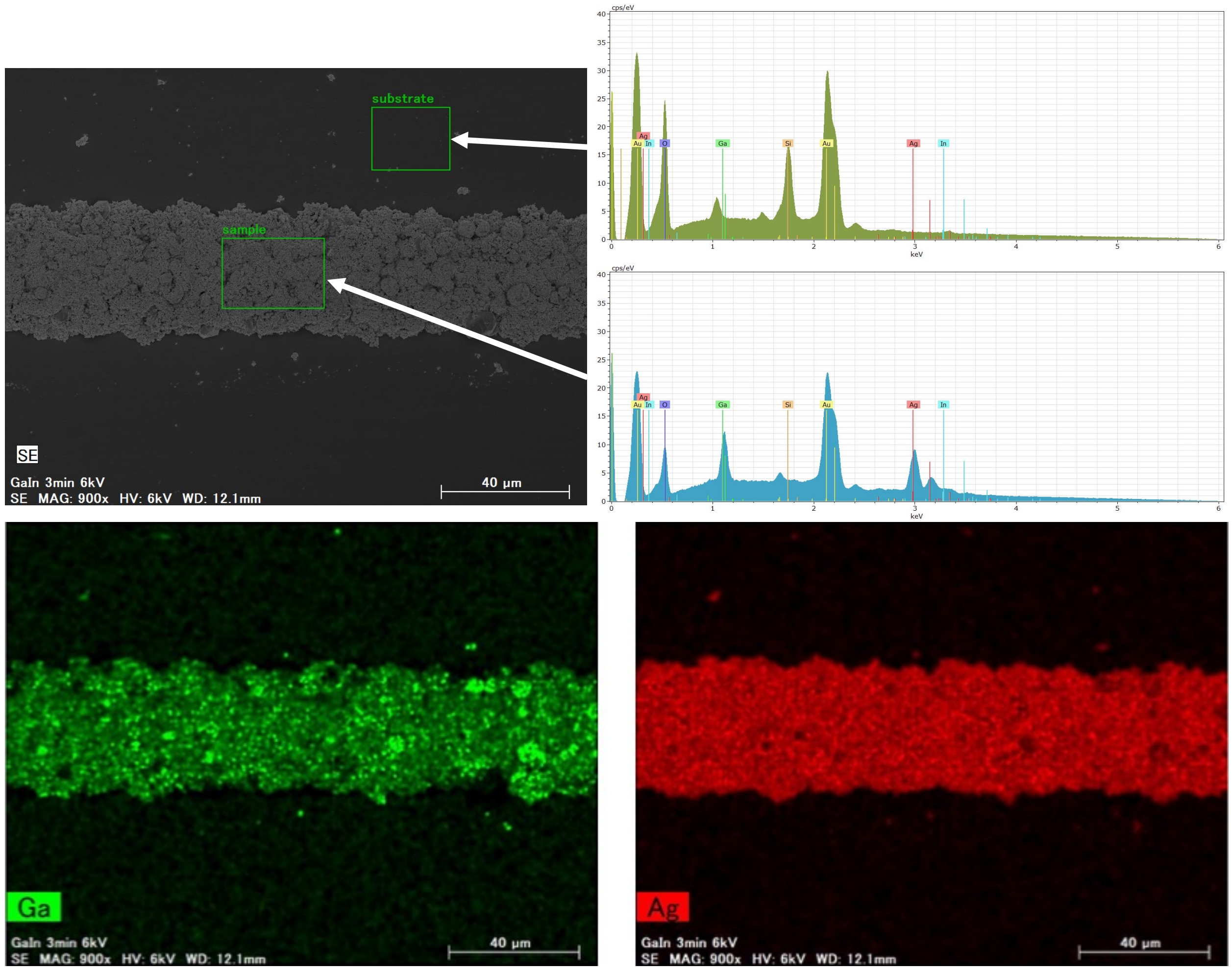

Figure S9. EDX spectra of the inside and outside of the processed line with galvanic replacement with 12.7 M $AgNO_3$ for 3 min and the corresponding EDX mapping of Ga and Ag. Acceleration voltage: 6 kV.

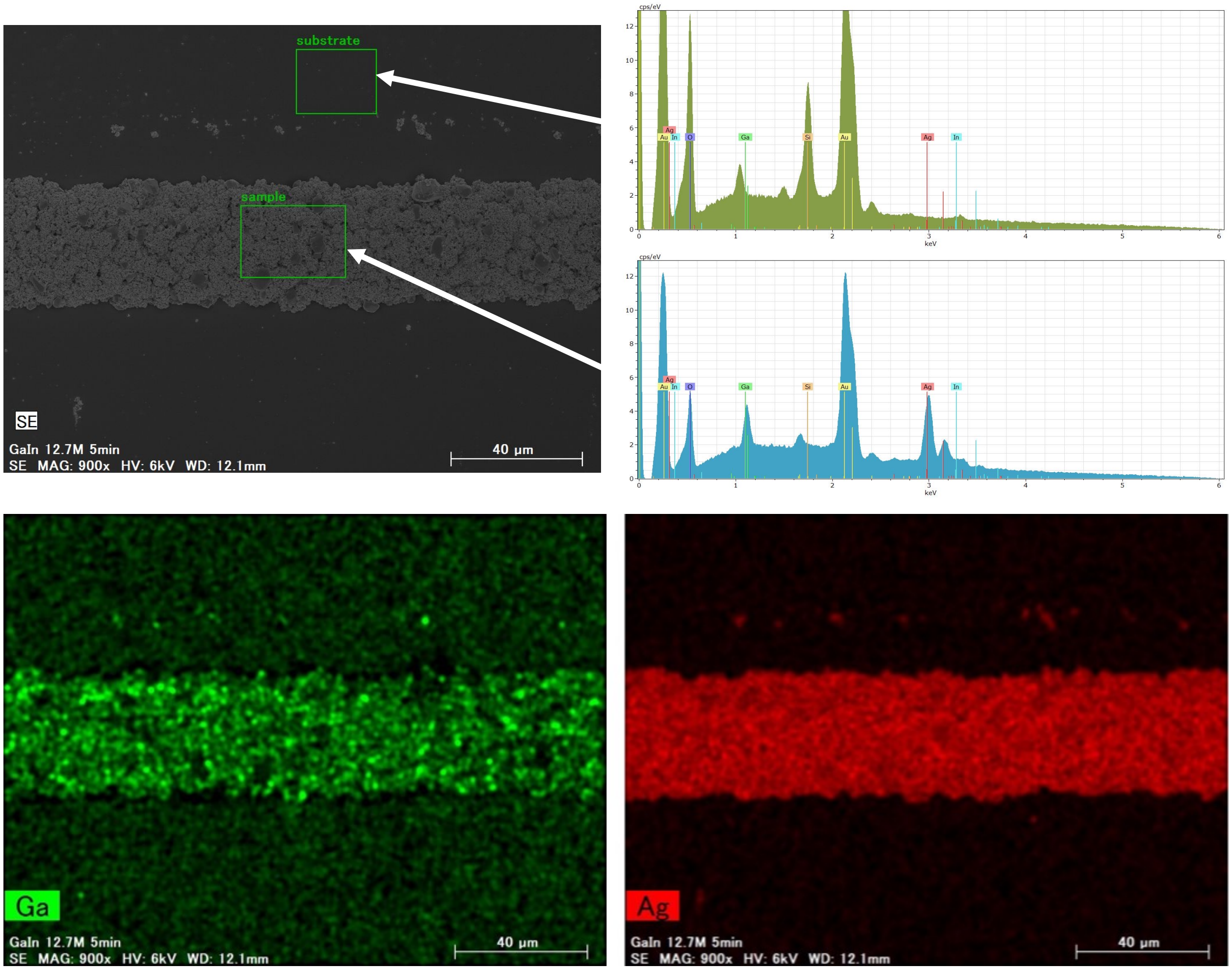

Figure S10. EDX spectra of the inside and outside of the processed line with galvanic replacement with 12.7 M $AgNO_3$ for 5 min and the corresponding EDX mapping of Ga, and Ag. Acceleration voltage: 6 kV.

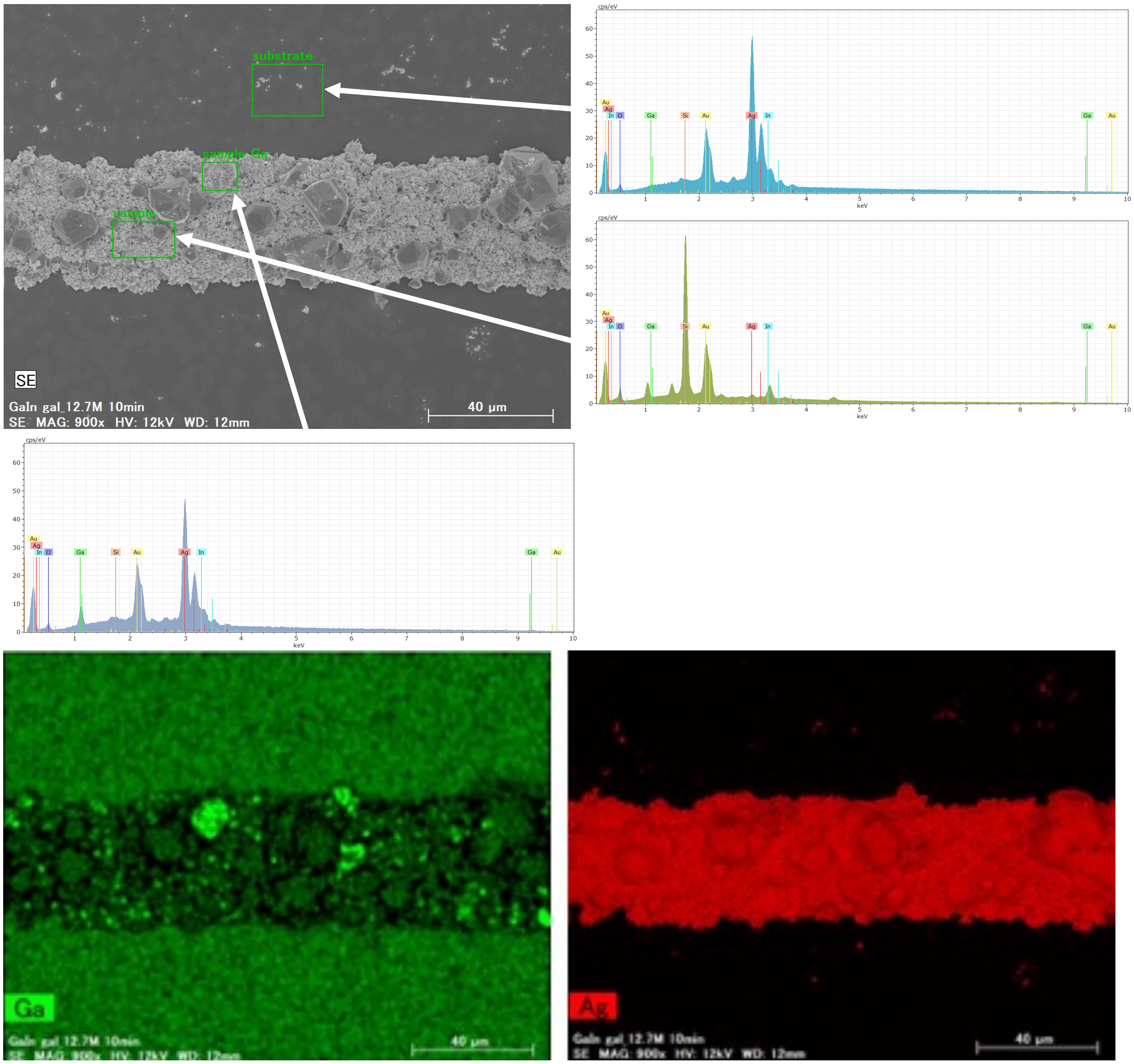

Figure S11. EDX spectra of the inside1, inside 2, and outside of the processed line with galvanic replacement with 12.7 $AgNO_3$ for 10 min and the corresponding EDX mapping of Ga and Ag. Acceleration voltage: 6 kV.