

Supplementary Materials

Room-Temperature Pressureless Bonding with Silver Nanowire Paste: Towards Organic Electronic and Heat-Sensitive Functional Devices Packaging

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Washing cycles effect on organic contents of AgNW pastes:

Figure S1 shows the TGA testing curves conducted at room-temperature up to 500 °C. As washing times increase, the weight loss dramatically decreased from 20% for one washing cycle to only 0.4% for three cycles. A small fluctuation is evident on the derived weight change curves at 300 °C, which suggests the organics were readily removed almost without residuals.

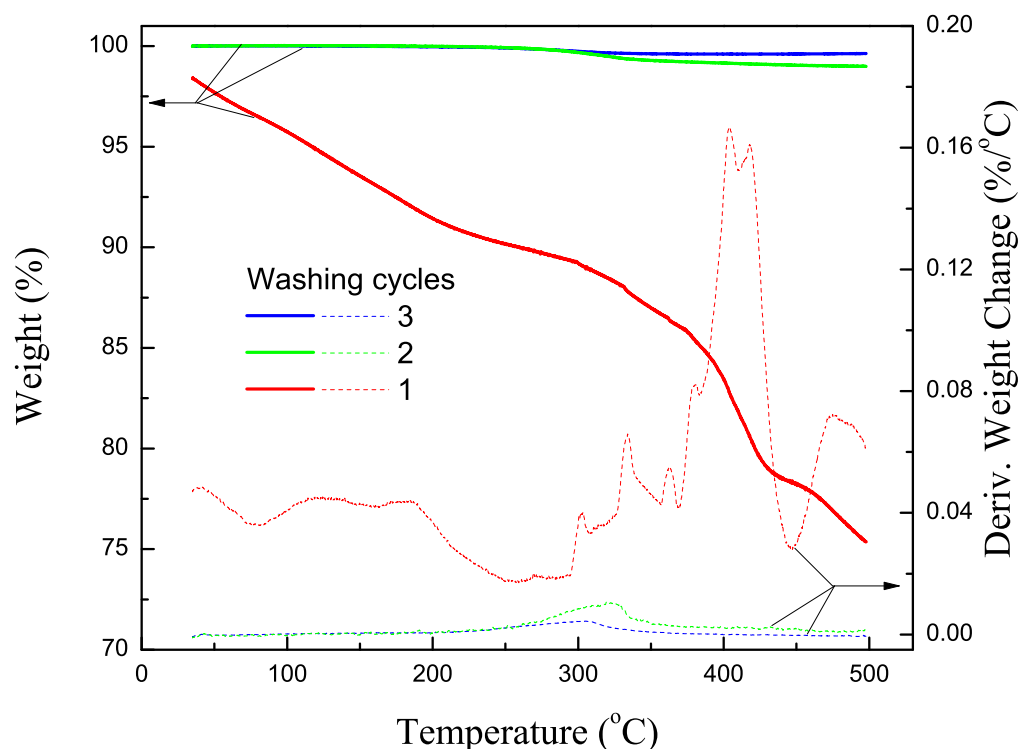


Figure S1. TGA curves of three pastes with different washing times using DI water. Solid lines are weight (%) and dashed for derivate weight change (%/°C).

Sintering behaviours of pastes with different washing times:

The TEM image inset in Figure 1b illustrates the coated organic shell (PVP) with 3 nm thick on the side of as-synthesized Ag NW due to the stronger interaction between PVP and {100} facets than that between PVP and {111} facets [1, 2]. This residual PVP from the synthesis process could be present at the interfaces of naowires and influence the sintering of the paste. Although PVP were strongly absorbed on side surfaces of Ag NWs and does not readily decompose at below 300 °C [3,4], the majority of this organic compound can be removed during the process of washing with DI water as previously shown on Cu NPs [5]. As such, it would be expected that wire surface free of organic coatings would be reactive and easily for Ag atom interdiffusion during sintering, which has been observed in silver nanoparticles [6].

The Ag NW pastes after washing two and three cycles were sintered at 100 °C, 200 °C and 300 °C. As shown in **Figure S2a**, the paste which was washed twice was stable and no significant bridge paths of nanowires were observed after 1 hour heating at 100 °C. When the temperature increased to 200 °C, the adjacent Ag NWs in 2 times washed sample could form the bridge path after 5 minutes as the arrows indicated in Figure S2b. Continually increase the temperature to 300 °C, Ag NWs changed into particles in Figure S2c because Ag NWs merged together due to the fast solid state diffusion process. The fresh paste of 3 times washings, which has the similar morphologies of Figure S2a, started to sinter and precipitate after one week at room-temperature. Ag NWs interconnected together, forming the cross wire junction or multiple terminal junctions, and constructed to networks as the arrows pointed out in Figure S2d. When the temperature increased to 200 °C, the Ag NWs after three washing cycles grew thinner or broken, see Figure S2e. Continually increase the temperature to 300 °C, the similar morphology, grown particles in Figure S2f, was observed as 2 times washed paste in Figure S2c.

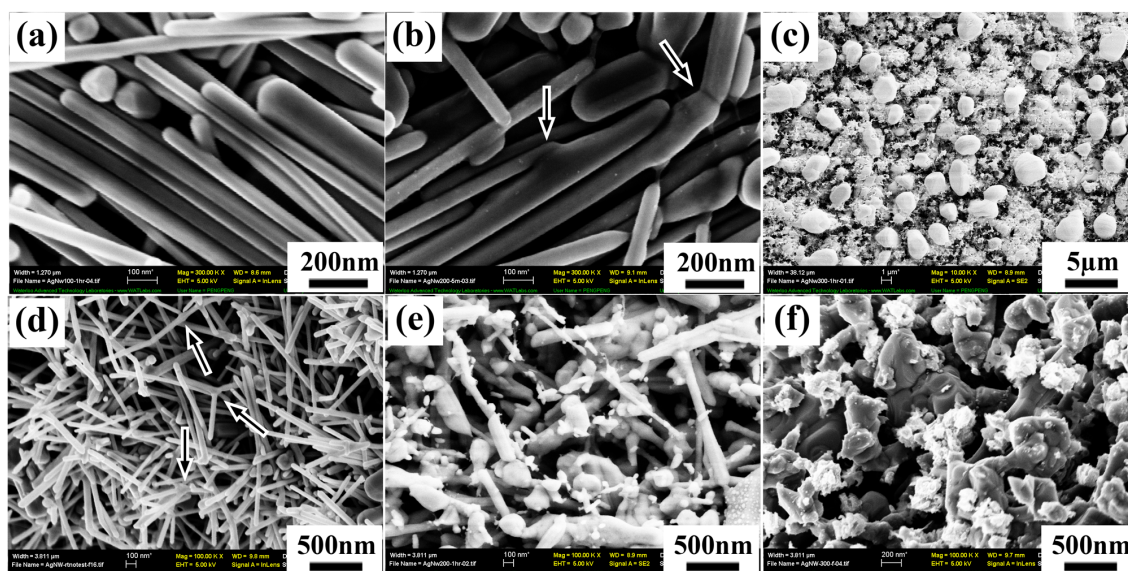


Figure S2. SEM images of sintered Ag NWs. Twice washed paste (a) 100 °C for 1 hour, (b) 200 °C for 5 minutes and (c) 300 °C for 1 hour. Three times washed paste sintered at (d)

room-temperature for 3 weeks, (e) 200 °C and (f) 300 °C for 1 hour. Arrows highlighted the interconnection of Ag NWs

Bonding and testing configurations:

Figure S3 illustrates the schematic diagram of the wire configuration during bonding process, tensile shear test configuration, joint size measurement and joint failure. After clamping each bonded sample into the grips as shown in Figure S3b, loading was applied. The measured strength of joints is the tensile shear strength due to the applied shear stress during the tensile testing, because two Cu wires were not coaxial. It was estimated by dividing the highest failure force value by the bonding area [5, 7, 8], $\sigma = F_{max}/A$ (N/mm² or MPa). The fracture area of samples was difficult to measure due to the unsymmetrical geometry of fracture region. Here, we used average bonding area to normalize the actual fracture area, which bonding area A was calculated by multiplying the maximum bonding length L by thickness D (see Figure S3c) of the Ag bonding material. Filler material fracture was shown in Figure S3d.

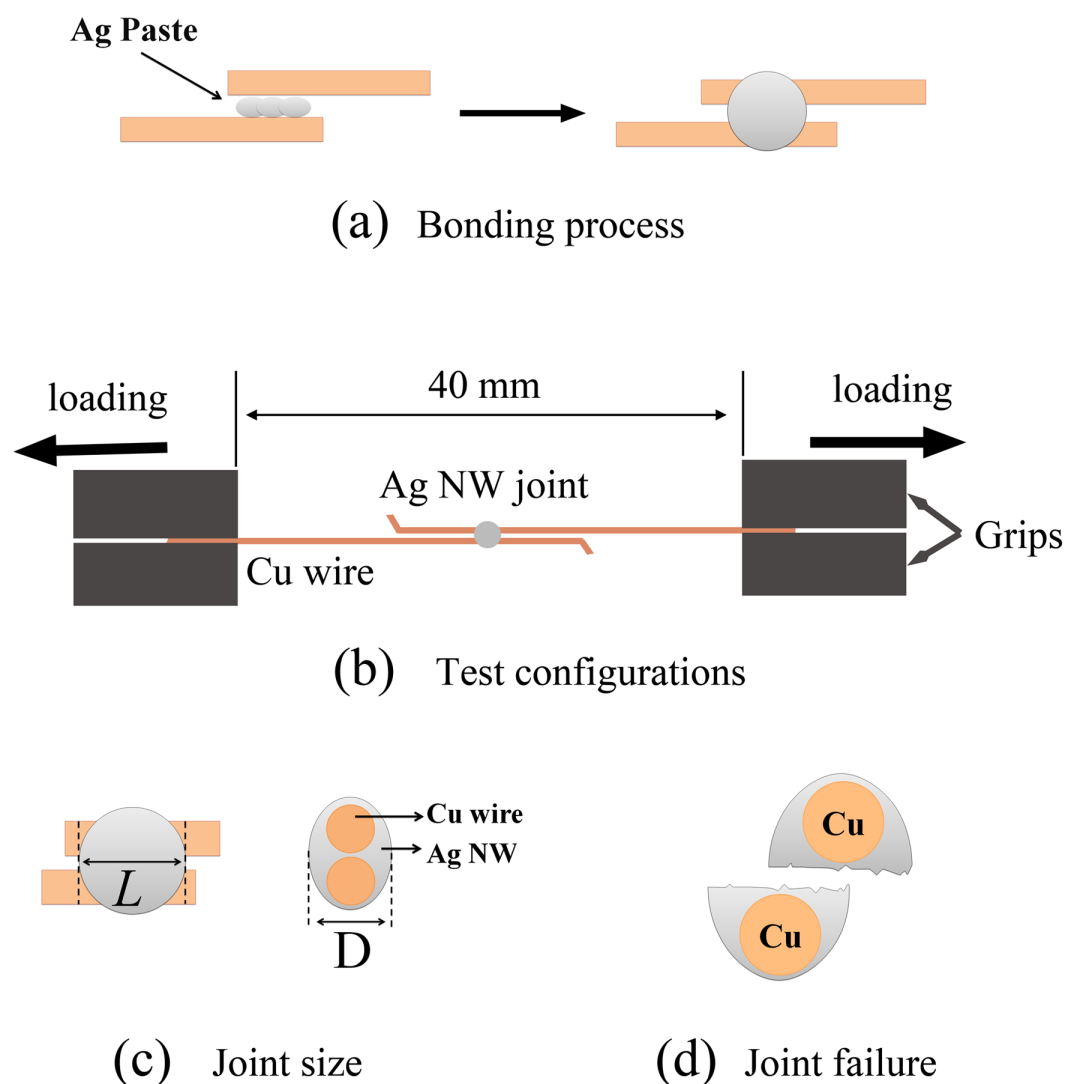


Figure S3. Schematic illustration of (a) wire configuration during bonding, (b) tensile shear strength testing of bonded samples: the starting distance between the grips was fixed at 40 mm, (c) L and D denote the bonding length and thickness of joint and (d) filler material fracture.

Interface of joint bonded at room-temperature:

Figure S4 shows the microstructures of cross sections of joint. Two Cu wires can be identified with a 20 μm gap filling with Ag NW paste and the interface between Cu and Ag matrix is very sharp in Figure S4a & b. In the interface as shown in Figure S4c, the metallurgical bond between the Cu wire and the Ag paste was found to be continuous. The

EDX line scanning shows the Ag and Cu elements could form a $\sim 0.5 \mu\text{m}$ transition layer by atoms diffusion.

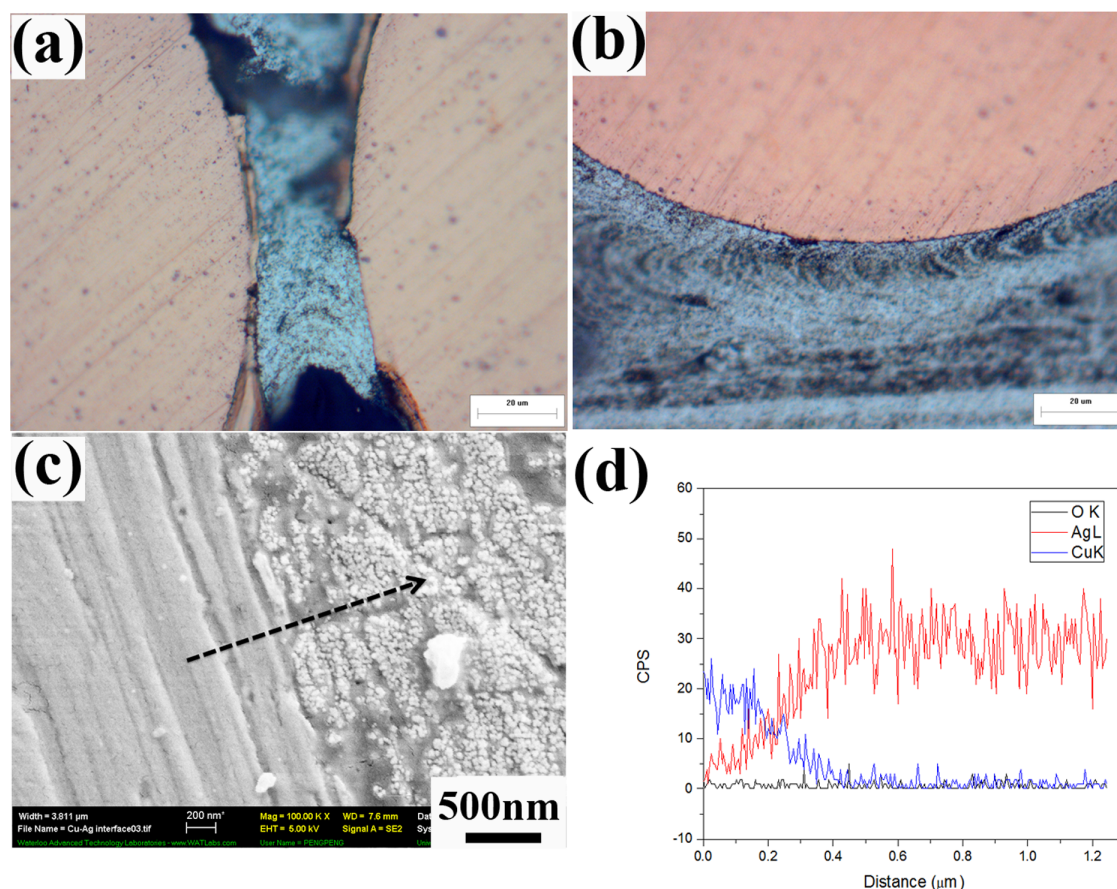


Figure S4. Microstructures of cross sections of Ag NW paste bonded Cu-Cu joints at room temperature: (a) Two Cu wires can be identified with a 20 μm gap filling with Ag NW paste; (b) Optical microscope image of clear interface of Cu and Ag matrix; (c) SEM image of bonded interface of cross section shows the bond is continuous and formed metallurgical bond between the Ag nanomaterials and Cu wire; Dashed arrow indicating (d) the EDX line scanning direction, Ag and Cu elements formed a 0.5 μm transition layer by atoms diffusion.

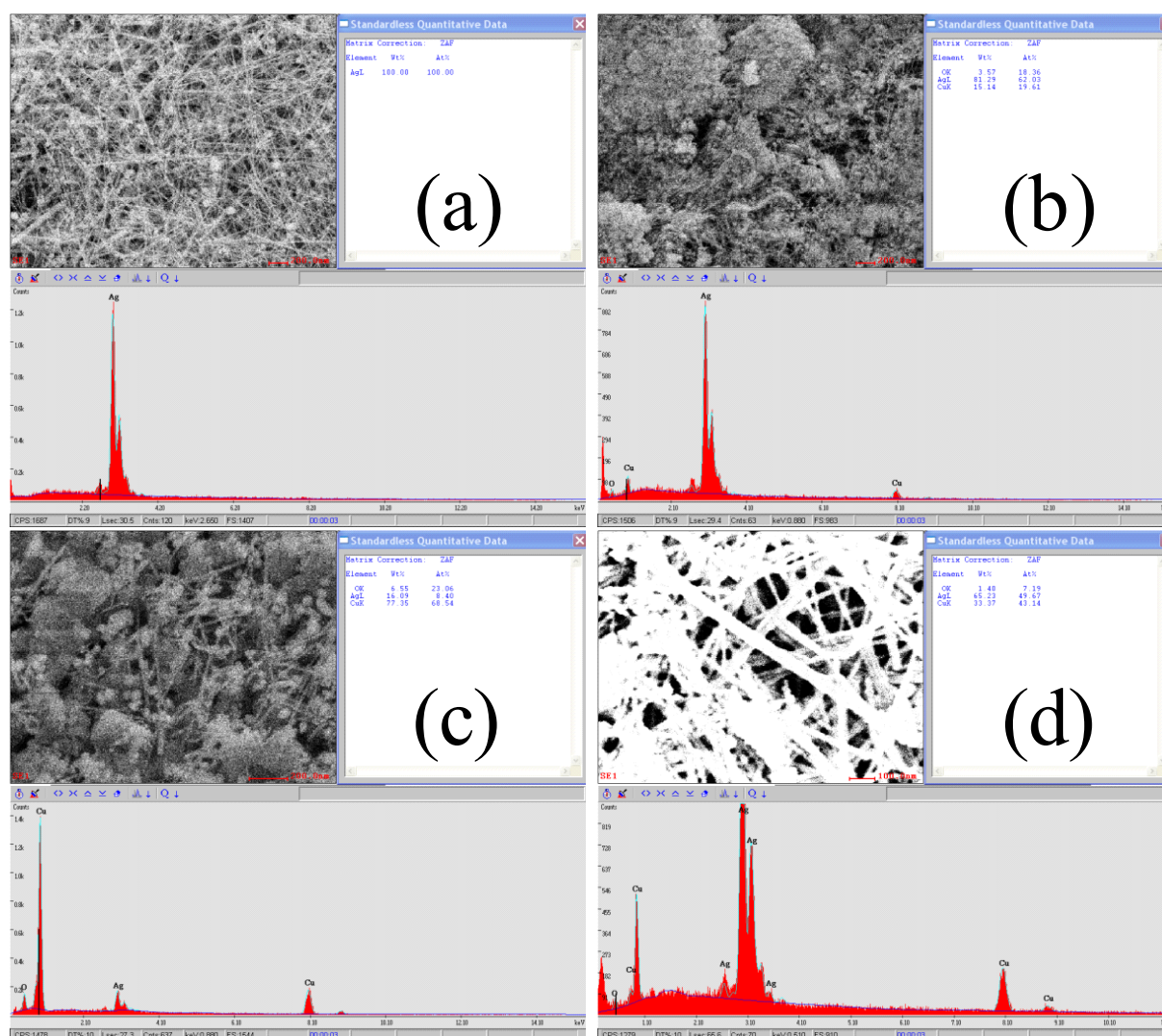


Figure S5. EDX results for (a) Ag matrix surface, (b) folded Ag NW layer, with particles attached on AgNW and (c) Cu wire surface with EDX results. The Cu wire surface of failure joint bonded at (d) 100 °C.

References

- [1] Y. Sun, Y. Yin, B.T. Mayers, T. Herricks, Y. Xia, *Chem. Mater.* **2002**, 14, 4736.
- [2] Y. Sun, B. Mayers, T. Herricks, Y. Xia, *Nano Lett.* **2003**, 3, 955.
- [3] X. Yuan, C. Li, G. Guan, Y. Xiao, D. Zhang, *Polym. Degrad. Stabil.* **2008**, 93, 466.
- [4] M. Zheng, M. Gu, Y. Jin, G. Jin, *Mater. Sci. Eng. B* **2000**, 77, 55.
- [5] J. Yan, G. Zou, A. Hu, Y. Zhou, *J. Mater. Chem.* **2011**, 21, 15981.

- [6] S. Magdassi, M. Grouchko, O. Berezin, A. Kamyshny, *ACS Nano* **2010**, 4, 1943.
- [7] O. Krammer, B. Sinkovics, *Microelectron. Reliab.* **2010**, 50, 235.
- [8] A. Hirose, H. Yanagawa, E. Ide, K. F. Kobayashi, *Sci. Technol. Adv. Mat.* **2004**, 5, 267.