Supplementary Material (ESI) for Journal of Materials Chemistry

Supplementary Information

A drastic reduction in silver concentration of metallic ink by use of single-walled carbon nanotubes decorated with silver nanoparticles

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Table S1 shows nAg-SWNTs dispersed in different solvents: DMF, α-terpineol, diphenyl disulfide/α-terpineol and SDS/DI water. All the samples were ultrasonicated at 540 W for 10 min, and nAg-SWNTs were aggregated in less than a week.

SP#1	nAg-SWNTs (0.2 mg) + DMF (10 ml)	 **15 min**	 **1 day**
SP#2	nAg-SWNTs (0.2 mg) + α-terpineol (10 ml)	 **15 min**	 **2 days**
SP#3	nAg-SWNTs (0.2 mg) + diphenyl disulfide (30 mg) + α-terpineol (10 ml)	 **15 min**	 **5 days**
SP#4	nAg-SWNTs (0.2 mg) + SDS (10 mg) + DI water (10 ml)	 **15 min**	 **7 days**

Table S1. nAg-SWNTs dispersed in different solvents by ultrasonication (540 W, 10 min).

Fig. S1 shows parametric analysis to find out the optimal concentration of metallic additives in the inks. The effect of the relative concentration between Ag nanoparticles with an average size of 3 nm and SWNTs on the conductivity of the ink is shown in Fig. S1a. The total concentration of nAg-SWNTs was fixed at 0.001 wt. %. The compositions of other ingredients were Ag nanoparticles(~30 nm): ethyl cellulose: NMP = 3: 0.588: 96.411 wt. %. The relative concentration could be controlled by adjusting the amount of benzyl mercaptan [S1,S2], and the maximum conductivity was observed at Ag nanoparticels(~3 nm): SWNTs = 30: 70 wt. %.

The conductivity of the ink as a function of the concentration of large Ag nanoparticles (~30 nm) is shown in Fig. S1b. The relative concentration between Ag nanoparticles (~3 nm) and SWNTs was fixed at 30:70 wt. %, and the total concentration of nAg-SWNTs was 0.001 wt. %. The other compositions were ethyl cellulose: NMP = 0.588: 92.411~98.411 wt. %. The conductivity of the ink was increased as the concentration of Ag nanoparticles (~30 nm) was increased from 1 wt. % to 3 wt. %. However, the increase in Ag nanoparticle concentration beyond 3 wt. % did not result in a further increase in the conductivity of the ink. Therefore, the optimal composition of Ag nanoparticles (~30nm) was found to be 3 wt. %.

As shown in Fig. S1c, the total concentration of nAg-SWNTs was investigated to obtain maximum conductivity of the ink. The relative concentration between Ag nanoparticles (~3 nm) and SWNTs was fixed at 30:70 wt. %. The corresponding compositions of other ingredients were Ag nanoparticles (~30 nm): ethyl cellulose: NMP = 3: 0.588: 96.408~96.412 wt. %. The maximum conductivity was obtained at 0.003 wt. % of nAg-SWNTs. A further increase in nAg-SWNTs led to the unstable dispersion and decrease in conductivity.

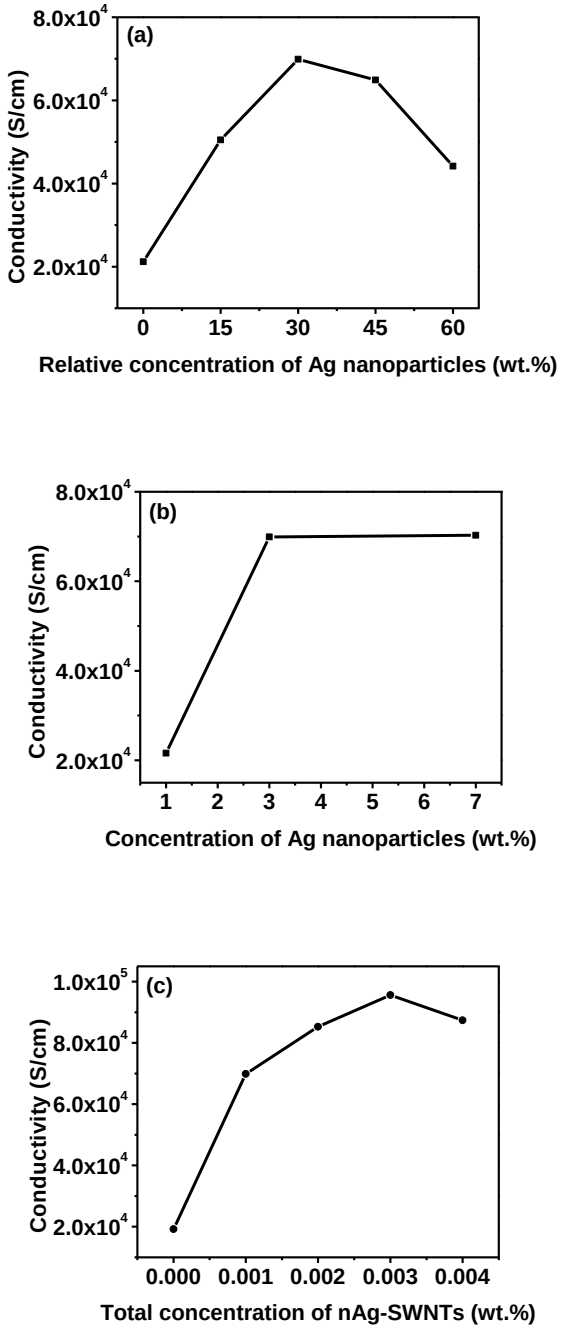

Fig. S1. Parametric analysis to find out the optimal concentration of additives. All the samples were cured at 350 ^{o}C (a) The effect of the relative concentration between Ag nanoparticles (~3 nm) and SWNTs on the conductivity of the ink. (b) The conductivity of the ink as a function of the concentration of Ag nanoparticles (~30 nm). (c) The conductivity of the ink as a function of the total concentration of nAg-SWNTs.

Fig. S2 shows the procedure to make the conductive specimen on a glass slide. A mold (20 × 5 × 0.055 mm) was defined on the glass slide using adhesive tape (Fig. S2a). The average thickness of the tape (~0.055 mm) was measured by a surface profiler (AS2Q). A top-view optical image is provided in the inset. In the next step, a 40 μl of metallic ink was dropped on the mold forming convex meniscus since the tape was hydrophobic (Fig. S2b). The thickness of the deposit after drying, removal of the tape and curing is shown in Fig. S2c. The height of the edge was significantly greater than that of the rest of flat central region. It is possible that nanoparticles adhered to the mold during the drying process. The central region showed flat geometry and the average thickness was found to be ~ 1 μm. Volume resistivity was measured at the center using a four-point probe method.

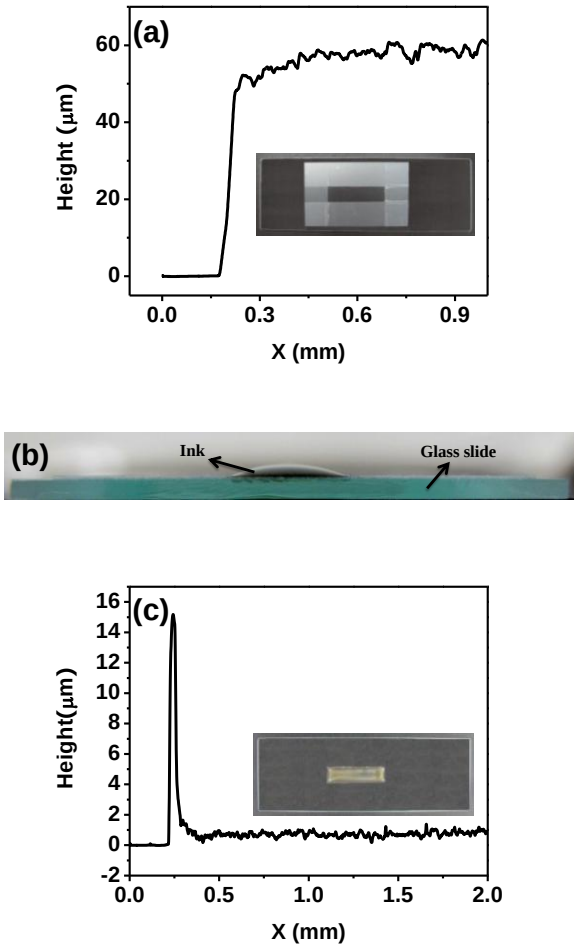

Fig. S2. The procedure to make the conductive specimen on a glass slide (a) The thickness of the adhesive tape on the glass slide. A top-view optical image is provided in the inset. (b) A side-view optical image after applying the metallic ink on the mold. (c) The thickness of the deposit after curing. A top-view optical image is provided in the inset.

Fig. S3 shows the X-ray diffraction analysis (Bruker, D8 Discover) of the conductive specimen on a glass slide. There was negligible change in the data before and after the curing at 350°C in air, and any noticeable peak related with the oxidized silver could not be observed [S3,S4].

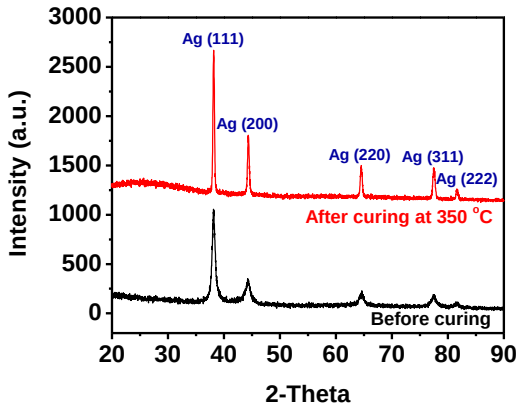

Fig. S3. XRD data of the conductive specimen before and after the curing at 350°C.

References

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