Graphene Inks for Printed Electronics

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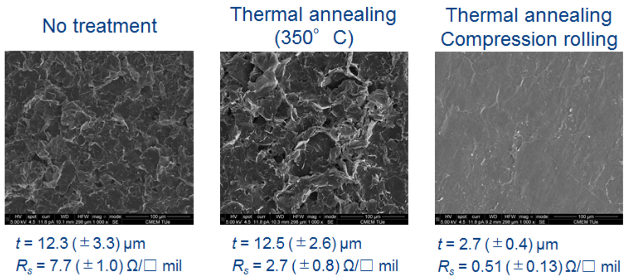
Low-cost high-throughput printing of solution processed electronics is a rapidly expanding field that already encompasses many large-scale applications such as roll-to-roll printed solar cells, including current collecting grids, displays, and radio frequency identification (RFID) devices. Here, solution-processed graphene holds considerable promise for printed electronics as it is widely available, inexpensive, flexible, and most importantly, highly conductive. [1]
For flexible electronic devices, e.g., organic photovoltaics, a sheet resistance < 10 Ω/□ mil is required, while for printed RFID antennas, one needs a few Ω/□ mil. [2]
Two graphene ink formulations with PVP (N-vinylpyrrolidone) or PU (poly(urethane)) as a binder were produced by high-shear mixing of expanded graphite (EG) (52.5 mg mL^{-1}) in appropriate solvents, followed by gelation through solvent exchange. [1] Several EG : binder ratios were tested, and the formulations which resulted in lower sheet resistances selected, namely EG 1:2 PVP, and EG 2 : 3 PU based formulations.
Electrical performance was tested by production of thin (< 13 µm) films at the surface of polyimide substrates. These films presented sheet resistance values around 8 and 23 Ω/□ mil, respectively for PVP or PU formulations.
Performing thermal annealing at 350 °C for 30 min resulted in a significant drop in sheet resistance to around 2 Ω/□ mil, while no considerable changes were observed in both conductors thickness.
When compression rolling was performed, thickness decreased to values under 4 µm, as a tile-like dense graphene stacking was formed, assuring low sheet resistance results, below 1 Ω/□ mil (Figure 1).
For applications in which thermosensitive substrates are required, thermal annealing temperature is limited. Therefore, the effect of performing annealing at temperatures lower than 350 °C was studied. It was observed that when using longer thermal annealing times (up to 24h) at temperatures as low as 200 °C, sheet resistance remains below 1 Ω/□ mil, after the compression rolling process.
These values can be compared with those reported from Karagiannidis et al. [2], which produced analogous inks using carboxymethylcellulose as a binder, obtaining sheet resistances of 2 Ω/□ mil after thermal annealing at 300 °C for 40 min.

References

[1] K. Arapov, H. Friedrich et al., Adv. Funct. Mater 26 (2016) 586
[2] P.G. Karagiannidis, A.C. Ferrari et al., ACSnano 11 (2017) 2742

Figures



Binder	Annealing T	Dry thickness / µm		Resistance (Ω/□ mil)	
	°C	Avr	SD	Avr (n=3)	SD
PVP	200	6	0	0.96	0.07
	250	4	1.7	0.72	0.02
	350	3	0.4	0.51	0.13
PU	200	4	0	0.93	0.11
	250	2	0	0.24	0.02
	350	2	0.3	0.28	0.09

Figure 1: Representative scanning electron microscopy images of PVP-based graphene ink films. Effect of post-treatment (compression rolling and thermal annealing) on conductors thickness and sheet resistance.