Graphene-Based Micro-Supercapacitors with Ultrahigh Power and Energy Densities

Zhong–Shuai Wu, Khaled Parvez, Xinliang Feng, and Klaus Müllen

Max-Planck-Institut für Polymerforschung, Ackermannweg 10, 55128 Mainz, Germany

wuzs@mpip-mainz.mpg.de

Abstract

Micro-supercapacitors are important on-chip micro-power sources for miniaturised electronic devices. Although the performance of micro-supercapacitors has been significantly advanced by fabricating nanostructured materials, developing thin-film manufacture technologies and device architectures, their power or energy densities remain far from those of electrolytic capacitors or lithium thin-film batteries. Here we demonstrate a novel class of all solid-state graphene-based in-plane interdigital micro-supercapacitors on both rigid and flexible substrates through micropatterning of methane plasma reduced graphene (MPG) films with a nanoscale thickness of 6~100 nm (Figure 1). Due to the high electrical conductivity (~345 S cm^{-1}) of the fabricated graphene films and the in-plane geometry of the microdevices, the resulting micro-supercapacitors deliver an area capacitance of ~80.7 μF cm^{-2} and a stack capacitance of ~17.9 F cm^{-3}. Further, they show a power density of 495 W cm^{-3} that is higher than electrolytic capacitors, and an energy density of 2.5 mWh cm^{-3} that is comparable to lithium thin-film batteries, in association with superior cycling stability. Such microdevices allow for operations at ultrahigh rate up to 1000 V s^{-1}, three orders of magnitude higher than conventional supercapacitors. Notably, the electrochemical performances of micro-supercapacitors are significantly enhanced by increasing the number of the interdigital fingers from 8 to 32 and minimizing the finger width from 1175 to 219 μm, highlighting the critical importance of adjusting the number and widths of the fingers in the fabrication of high-performance micro-supercapacitors. Micro-supercapacitors with an in-plane geometry have great promise for numerous miniaturised or flexible electronic applications.

References

[1] Z. S. Wu, K. Parvez, X. L. Feng, K. Müllen, Nature Communications, 2013, 4, 2487.
[2] Z. S. Wu, X. L. Feng, H. M. Cheng, National Science Review, 2014, DOI: 10.1093/nsr/nwt1003.
[3] Z. S. Wu, K. Parvez, X. L. Feng, K. Müllen, Journal of Materials Chemistry A, 2014, DOI: 10.1039/C4TA00958D

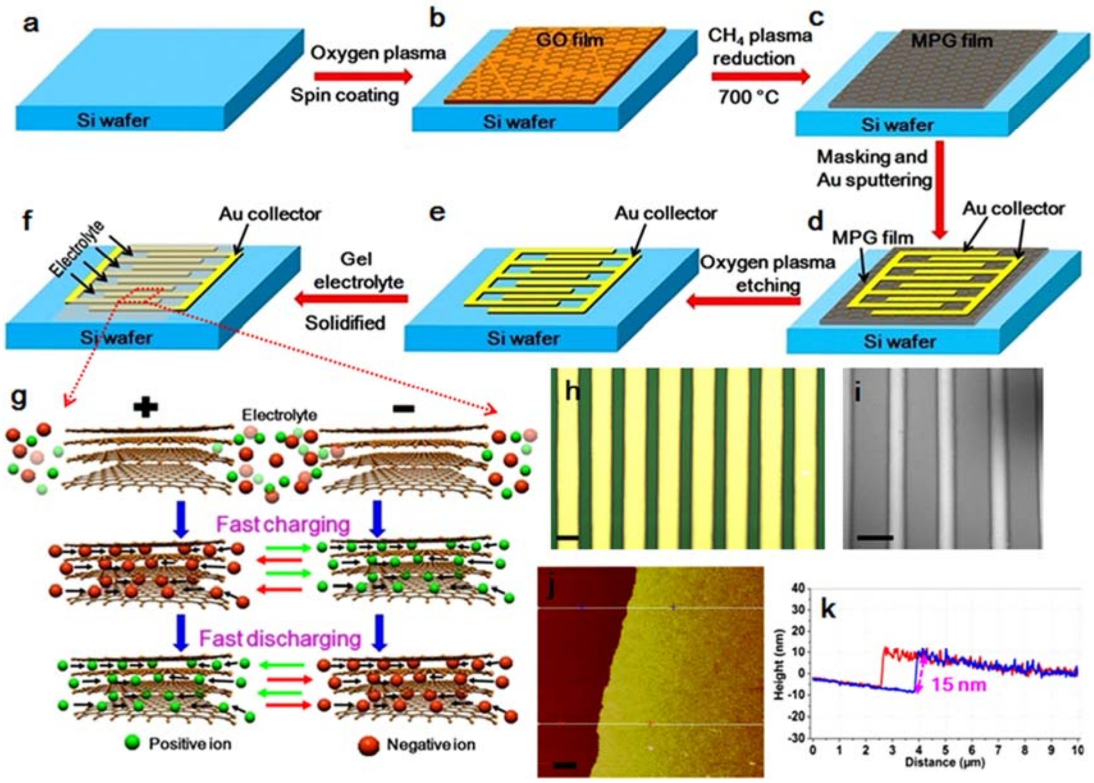

Figure 1 Design of MPG-based micro-supercapacitors (MPG-MSCs) on a silicon wafer. (**a-f**) Schematic illustration of the fabrication of MPG-MSCs made up of 30 interdigital fingers integrated onto a silicon wafer. The fabrication process flow includes (**a**) oxygen plasma surface treatment of silicon, spin coating of the GO solution on surface-modified silicon, (**b**) CH_4 plasma reduction, (**c**) masking pattern and deposition of gold current collector, (**d**) oxidative etching in oxygen plasma, (**e**) drop casting of the H_2SO_4/PVA gel electrolyte, and (**f**) solidification of the gel electrolyte. (**g**) In-plane geometry of MPG-MSCs, revealing that the ions between the electrode gaps can be rapidly transported along the planar graphene sheets with a short diffusion length. (**h**) Optical and (**i**) SEM images of the microelectrode patterns. Scale bars, 200 μm. (**j**) Atomic force microscopy image of the MPG film electrode after etching by oxygen plasma and removal of Au by a KI/I_2 aqueous solution. Scale bar, 1 μm. (**k**) Uniform thickness of ~15 nm, indicated by the height profile of the MPG film.