3.3 Inkjet printing as a facile route towards low cost electrochemical energy storage

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The push towards self-powered electronics through energy harvesting, calls for the development of high-performance supercapacitors that can enable sustained, autonomous operation of electronic devices for applications such as wearable electronics, biomedical implants and internet-of-things. Low cost supercapacitors with high energy density can potentially serve as commercially attractive devices towards stand-alone and maintenance-free power sources when combined with energy harvesters. Therefore, great efforts have been devoted in either extending the energy density of these storage systems by using pseudocapacitive electrode materials, which store energy by fast surface redox reactions enhancing the storage ability of the system, or/and by utilising high-throughput, low cost fabrication techniques to keep the cost/stored-energy ratio low. Typical fabrication methods, such as photolithography and electrode rolling/stacking that are commonly used in conventional energy storage systems, have not only caused the devices to lack a variety of form factors and flexibility needed for countless new Internet-of-Things applications, but also rose the overall cost of the devices due to excessive material waste and complex processing. In the past decade, the development of digital printing technology in the field of printed electronics, has triggered an explosion of new ideas and alternative fabrication strategies that led to lean and cost-efficient manufacturing processes. In this research, we demonstrate the fabrication and integration of high-performance, fully solution processed, co-planar NiO micro-supercapacitors through inkjet printing (Figure 1). Inkjet printing is a readily scalable process and the devices can be fabricated on large, flexible substrates at the fraction of the cost of traditional supercapacitor fabrication methods. The nanoparticle-based thin film NiO electrodes showed up to 14 orders of magnitude higher electrical conductivity than single crystal NiO. The enhanced conductivity of the electrodes was reflected in the low relaxation time constant of just 30 ms, which is among the lowest achieved for any supercapacitor. A magnesium perchlorate-based aqueous electrolyte with extended operating voltage window was developed to enable the operation of the devices up to 1.5 V. The devices showed remarkable areal and volumetric specific capacitances of up to 155 mF cm⁻² and 705 F cm⁻³ respectively, surpassing a few of the best micro-supercapacitors known to date. This work provides a compelling platform to simplify the fabrication process of supercapacitors, with focus on digital design, low cost scalable manufacturing, and direct integration with printed electronics.

References

Figure 1. (a-d) Scalable fabrication process of NiO supercapacitors through inkjet printing.