SUMMARY

This work presents the first demonstration of atomic layer deposition (ALD) ruthenium oxide (RuO₂) and its conformal coating onto vertically aligned carbon nanotube (CNT) forest as supercapacitor electrodes. Specific accomplishments include:

1) Successful demonstration of ALD RuO₂ deposition,
2) Uniform coating of RuO₂ on a vertically aligned CNT forest
3) Ultra-high specific capacitance from the prototype electrodes at 100 mF/cm² under a scan rate of 100 mV/s.

CONCEPT

ALD RuO₂ is deposited using ruthenium bis(ethylcyclopentadienyl) (Ru(EtCp)₂) and oxygen as precursors (Fig. 1). From grazing-incidence x-ray photoelectron spectroscopy (GIXPS) analyses, it is found that a deposition temperature of 350–400°C achieves good RuO₂ deposition (Fig. 2). The ALD-RuO₂ layer stores and discharges energy through surface reduction-oxidation (redox) reactions (Fig. 3).

Fig. 1 Schematic of ALD RuO₂ process with alternating Ru(EtCp)₂ and O₂ pulses.

Fig. 2 % O₂ in ALD RuO₂ thin-films.

Fig. 3 Conceptual illustration of the ALD RuO₂-coated CNTs.

CHARACTERIZATION

Fig. 4: a) Cross-sectional SEM image of RuO₂-coated CNTs, b) TEM image of a single coated CNT

RESULTS

Fig. 5 shows cyclic voltammetry measurements of the ALD RuO₂-coated CNT supercapacitor compared to an uncoated (“bare”) CNT supercapacitor. The ALD RuO₂-CNTs have a specific capacitance of 100 mF/cm², one of the best values in the literature [1, 2]. The supercapacitor performance of the ALD RuO₂-CNTs is approximately fifty times that of the uncoated CNTs.

The Nyquist plot in Fig. 6 shows that the device has an equivalent series resistance (ESR) of 7 Ω, one of the lowest reported values.

Rapid charge-discharge characteristics have been demonstrated and remained stable over time, as shown in Fig. 7.

REFERENCES


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