Direct growth of vertically aligned single-walled CNTs on conducting substrate and its electrochemical performance in ionic liquids

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Abstract
We report fabrication of vertically-aligned single-walled carbon nanotube (VA-SWCNT) electrodes for a symmetric electrochemical capacitor using a simple ethanol-based CNT growth system. From the CNT direct growth technique, the electrode was easily prepared, and consequently assembled with ionic liquid as electrolyte. VA-SWCNTs were directly grown on conducting SUS 310S foils in which the binder material was not incorporated in the capacitor structure. This capacitor demonstrated excellent gravimetric capacitance and a high rate capability. From the cyclic voltammetric analysis, the capacitance was contributed not only from the ideal double layer capacitance, but also from faradaic processes that might have occurred during charge-discharge. Other than the capacitance, the VA-SWCNT capacitor was also measured by using frequency response (impedance) and charge-discharge analyses.

1. Introduction
Nanocarbon materials, especially CNTs have been focused as a highly-potential electrode material for energy storage devices due to their remarkable electrical charge storage ability. In particular, the significance of SWCNTs as electrode material includes not only the large surface area for electrolyte ion accessibility, but also chemical stability and excellent conductivity [1, 2]. For high-performance electrochemical capacitors (ECs), it is desirable to directly grow aligned CNTs onto conducting substrates to prepare the electrodes. In the case of entangled CNTs, the electrode might have large internal resistance because it includes binder materials which are less conductive and may become barriers in the access paths for electrolyte ions. To meet this requirement, we employed the alcohol catalytic CVD growth technique, and several obstacles to use CNTs as electrode materials were eliminated.

2. Results and discussion
First, ca. 50-μm VA-SWCNT forests were directly-grown on SUS 310S foils. VA-SWCNTs were catalytically-grown on SUS 310S foils from cobalt (Co, 0.5 nm) and thermally-oxidized aluminum oxide (Al-O, 20 nm). This is a critical technology to be highlighted for the development of ECs [3]. The presence of single-walled type CNTs was confirmed by various analyses. Heat-treatment process at 300 ^{o}C, 30 min was carried out after VA-SWCNT growth to prepare heat-treated (HT)-SWCNT electrode. Significant electrochemical performance of HT-SWCNT electrode in [EMIM][Tf_2N] electrolyte will be discussed. At 1 mV s^{-1} of CV scan rate, the C_{sp} was calculated to be 584 F g^{-1} (0.0 - 4.0 V potential). From the charge-discharge analysis at 50 A g^{-1} current density, HT-SWCNT ECs were tested up to but not limited to 500 cycles, which resulted only in 12 % capacitance loss. The success in various electrochemical measurements proved that the VA-SWCNTs had excellent electrical contact with SUS 310S foil.

3. Conclusion
From VA-SWCNT capacitor, a simple heat-treatment resulted in specific capacitance of > 500 F g^{-1} and high rate capability up to 1,000 mV s^{-1}. Based on the CV analyses, this high value was contributed from both double layer and faradaic capacitances. Overall, excellent achievements of VA-SWCNT-based ECs can be mainly attributed to the high charge storage capability of IL ions on the VA-SWCNT surfaces, and good electrical contact between VA-SWCNTs and SUS 310S foil. The dynamic lifetime of the electrode can be linked to the quality of SWCNTs grown from ethanol-based CVD. This work strongly supports the potential of VA-SWCNT electrode for industrialization, especially for usage in multi-scale power applications.

References
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