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## Synergistic effects of dual nano-type electrode of NiCo-nanowire/NiMn-nanosheet for high-energy supercapacitors

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## ABSTRACT

A unique three-dimensional hybrid NiCo(CO<sub>3</sub>)(OH)<sub>2</sub> nanowire/NiMn(CO<sub>3</sub>)(OH)<sub>2</sub> nanosheet composite was fabricated using a facile hydrothermal method as a binder-free electrode directly grown on Ni foam for supercapacitors. We examined the synergistic effect by fabricating Ni-Co-Mn ternary electrodes that used Ni-Co with a large specific surface area and Mn with a very high theoretical capacity. The new hybrid electrode had good electrochemical characteristics, exhibiting remarkably high specific capacitances of 1673.3 and 453.0 F g<sup>-1</sup> at 3 and 15 A g<sup>-1</sup>, respectively. Compared with other samples, the capacitance showed less reduction as the current density increased. This result indicates stable electrode properties with increasing voltage. The cycling stability of the hybrid NiCo(CO<sub>3</sub>)(OH)<sub>2</sub>/NiMn(CO<sub>3</sub>)(OH)<sub>2</sub> composite was measured as 82.1% after 5000 cycles. Additionally, we fabricated an asymmetric supercapacitor employing the NiCo(CO<sub>3</sub>)(OH)<sub>2</sub>/NiMn(CO<sub>3</sub>)(OH)<sub>2</sub> composite as the positive electrode and graphene as the negative electrode, which exhibited a high energy density of 27.2 W h kg<sup>-1</sup> at a power density of 702.7 W kg<sup>-1</sup> and a remarkable cycling stability, with 89.4% capacitance retention after 5000 cycles. Thus, for the first time, we investigated the dual nano-type structure of an NiCo(CO<sub>3</sub>)(OH)<sub>2</sub> nanowire/NiMn(CO<sub>3</sub>)(OH)<sub>2</sub> nanosheet electrode for supercapacitors and obtained satisfactory results.

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## 1. Introduction

The 21st century is a period of change, characterized by the fourth industrial revolution and 5G. Therefore, all human life will be related to digital equipment that will require a small and high-capacity storage device. Additionally, high-energy storage devices are required owing to the emergence of renewable energy and hybrid industry [1,2]. Among the various power source devices, supercapacitors are attractive because they are eco-friendly and provide a high-capacity energy-storage system. Recently, two interesting types of supercapacitors have been studied, with different charge-storage mechanisms: electrical double-layer

capacitors using C-based active materials and faradaic capacitors using redox-based faradic reactions [3–5]. Among them, the faradaic capacitors we studied have the high specific energy of a capacitor as well as the redox characteristic of a battery [6]. Regarding the electrode material, good electrochemical characteristics are required, including an excellent electrical conductivity, a large specific surface area, and no reactivity with the electrolyte. To satisfy this requirement, cathode materials based on RuO<sub>2</sub> have been actively studied, which theoretically have a high capacity exceeding 1000 F g<sup>-1</sup> [7,8]. However, these materials are rare and expensive and require the use of electrolytes that are environmentally harmful, making commercialization difficult. Therefore, to replace them, studies on metal oxides having a relatively low cost and high capacity have been continuously performed. In this respect, transition metals have been widely used as cathode materials. Currently, transition-metal oxides/hydroxides such as NiO [9], MnO<sub>2</sub> [10], CuO [11], Co<sub>3</sub>O<sub>4</sub> [12], and Ni(OH)<sub>2</sub> [13] and their binary arrays are widely studied as the positive electrode material for faradaic capacitors owing to their eco-friendly nature, low cost,

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