Green device, Sustainable electronics

Wood-derived semiconducting nanomaterials with customizable 3D structures and functions

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Researchmap https://researchmap.jp/hkoga?lang=en

Abstract

Semiconductor nanomaterials with 3D network structures have unique properties such as large specific surface area, high permeability, and electrical conductivity that make them suitable for adsorption, separation, and sensing applications. However, conventional semiconductor nanomaterials are limited in the designability of their 3D structures and the tuning range of their electrical properties, which greatly restricts their actual functions and applications.

In this context, we have developed a new technology for designing 3D structures and tuning electrical properties by stepwise carbonization using "nanopaper," a paper derived from wood cellulose nanofibers. The as-developed "nanopaper semiconductor" enables 3D structure design at the nano- to micro- to macro-scale and systematic control of electrical properties at the insulator to quasi-conductor level (Figure 1). These features outperform conventional semiconductor nanomaterials and enable customization of 3D structures and functions according to purpose and application. In actual, they have demonstrated excellent performances in a wide range of applications, from sensor devices to energy generation devices (Figure 2).

Background & Results

Nano- to micro- to macro-scale 3D structure design and electrical property tuning are rational strategies to control functions and applications of semiconductor nanomaterials. However, conventional semiconductor nanomaterials and technologies have limited the scope of 3D structure design and tuning of electrical properties. In other words, the nano-micro-macro trans-scale 3D structure design and wide tuning of electrical properties have not yet been achieved by a single semiconductor nanomaterial.

In this study, we have developed semiconductor nanomaterials with widely and systematically tunable electrical properties by stepwise carbonization of "nanopaper" derived from wood cellulose nanofibers. The tunable range of electrical properties of this "nanopaper semiconductor" covers electrical resistivity: 10^{13} to 10^{-2} Ω cm (insulator to quasi-conductor) (Figure 1a), carrier type: p- or n-type, and carrier mobility: 0.235 to 2.59 cm^2 V^{-1} s^{-1}. Furthermore, by applying the paper-specific structural design techniques (spatially-controlled drying, embossing, origami, and kirigami), we have achieved controlling 3D structure of the nanopaper semiconductor at the trans-scale from nano- to micro- to macro-scale (Figure 1b). Both the wide tunability of electrical properties and nano-micro-macro trans-scale designability of 3D structures are notable features of the nanopaper semiconductor that are better than those of previously reported 3D semiconductor structures. These features enable customization of function and structure of the nanopaper semiconductor, according to purpose and application. In actual, the nanopaper semiconductor provided not only the tunable functionality for applications ranging from water-vapor-selective sensors (Figure 2a) to biofuel cell electrodes for energy generation (Figure 2b), but also the designability of macroscopic device configurations for stretchable and wearable applications.

Significance of the research and Future perspective

This research will create new value for wood-derived cellulose nanofibers as semiconductors, and further development of their functions and applications is expected. In the future, this finding will contribute to the realization of sustainable electronics derived from biological resources that do not depend on metals or petroleum resources.

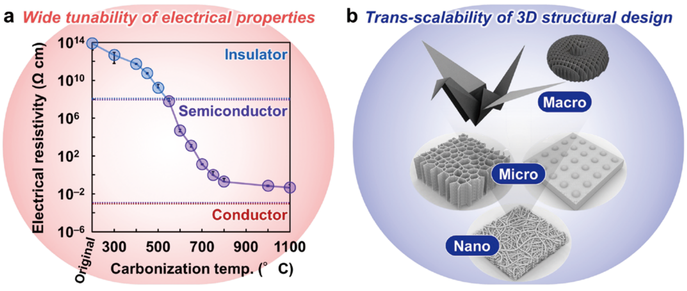

Figure 1

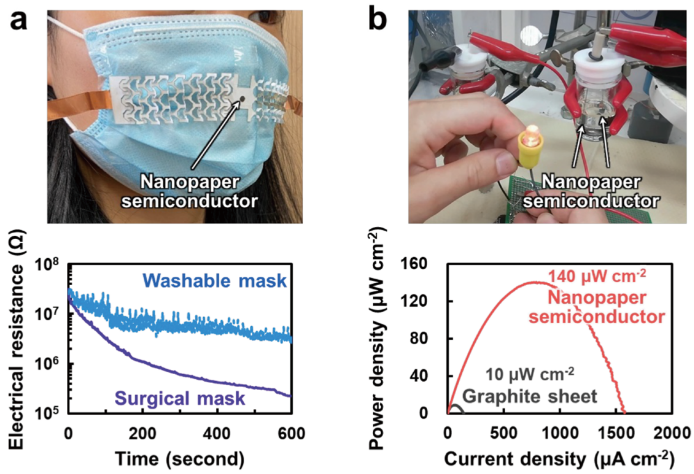

Figure 2

Patent

Treatise: Koga, Hirotaka; Nagashima, Kazuki; Suematsu, Koichi et al. Nanocellulose paper semiconductor with a 3D network structure and its nano–micro–macro trans-scale design. ACS Nano. 2022, 16 (6), 8630-8640. doi: 10.1021/acsnano.1c10728

URL

Keyword: nanocellulose, semiconductor, sensor device, energy generation device