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Research paper

Fabrication of silicon nanowires based on-chip micro-supercapacitor

Ankur Soam [a,b], Nitin Arya [a], Aniruddh Singh [a], Rajiv Dusane [a,*]

[a] Semiconductor Thin Films and Plasma Processing Laboratory, Department of Metallurgical Engineering and Materials Science, Indian Institute of Technology Bombay, Mumbai 400076, India

[b] Present address: Nanomaterials and Device Fabrication Laboratory, Center for Nanoscience and Nanotechnology, Siksha O Anusandhan University, Bhubaneswar 751030, Odisha, India

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ABSTRACT

An on-chip micro-supercapacitor (μ-SC) based on Silicon nanowires (SiNWs) has been developed by Hot-wire chemical vapor process. First, finger patterned electrodes of Al were made on a silicon nitride coated Si wafer and SiNWs were then grown selectively on the Al electrodes. μ-SC performance has been tested in an ionic electrolyte and a capacitance of 13 $\mu F/cm^2$ has been obtained by the μ-SC. The resulted μ-SC can be exploited to store the harvesting energy in micro-electro-mechanical-systems and coupled with battery for peak power leveling. Low temperature growth of SiNWs at 350 °C makes it suitable for prospective flexible electronics applications.

1. Introduction

Efficient energy storage and its delivery is always a necessity for operating gadgets remotely. Energy in form of electrical energy is the most suitable one and hence batteries and supercapacitors are in great demand. The future development towards making mobile or remote devices more efficient and smaller by reducing their size and weight has increased the need of an energy storage scheme on a chip [1–3]. Presently the working life of this system depends on the lifespan of the battery used to supply the needed power for all the functions. The limited life of battery restricts the long term use of a device [4–6]. In this regard replacing the battery with the SC could results in increasing the lifespan of a device and making it almost maintenance free. To scale down the SC technology on a chip has been a great challenge as its electrode materials are not outfitted with the micro fabrication processes. Most of the studies are currently dedicated to the design of μ-SC with different forms of carbon such as carbon nanotubes (CNTs) [7], graphene [8,9] and carbide-derived carbon [10,11]. Integrating these materials in μ-SC is still a great challenge because of involvement of complex, multiple and high temperature steps [7,11].

Recently, SiNWs with high surface area have been envisioned to be a well-suited electrode material for μ-SC [12–20]. In these studies the electrochemical properties of SiNWs have been performed either in three electrode configuration [13,15,18,19] or similar to the macroscopic supercapacitors in sandwich configuration by taking two identical electrodes [19–22], which are easy to be fabricated. Till date, full integration of SiNWs based μ-SC has not been demonstrated on a Si wafer. It is thus necessary to integrate SiNWs μ-SC on a Si wafer by simple and cost-effective methods. Therefore, we have developed a μ-SC of SiNWs on a Si wafer and investigated its electrochemical properties. Moreover, low growth temperature for SiNWs using hot wire chemical vapor processing (HWCVP) is favorable for flexible substrates. This device can be exploited in microelectronics devices such as maintenance-free implantable biosensors, wireless sensors network, micro-electro-mechanical-systems (MEMS) and portable electronics devices to store the harvested energy.

2. Experimental details

A Si wafer (n-type with ⟨1 0 0⟩ orientation) cleaned ultrasonically in DI water, isopropanol was used as a substrate. A layer of hydrogenated amorphous silicon nitride (a-SiNx:H) film of thickness ~400 nm was deposited by HWCVP on the cleaned Si-wafer to provide an insulating isolation layer to the electrodes. SiNx film was deposited by using a gas mixture of SiH_4, NH_3 and N_2 gases in a particular ratio at a substrate temperature of 150 °C, filament temperature of 1800 °C and a chamber pressure of 200 mTorr by HWCVP technique. Al thin film of thickness ~200 nm in form of finger pattern was then deposited on the SiNx deposited Si wafer by using a shadow metal mask, which works as the current collector for SiNWs. After that, Sn film was deposited selectively

* Corresponding author at: Semiconductor Thin Films and Plasma Processing Laboratory, Department of Metallurgical Engineering and Materials Science, Indian Institute of Technology Bombay, Mumbai 400076, India.

E-mail address: ankursoam007@gmail.com (A. Soam).

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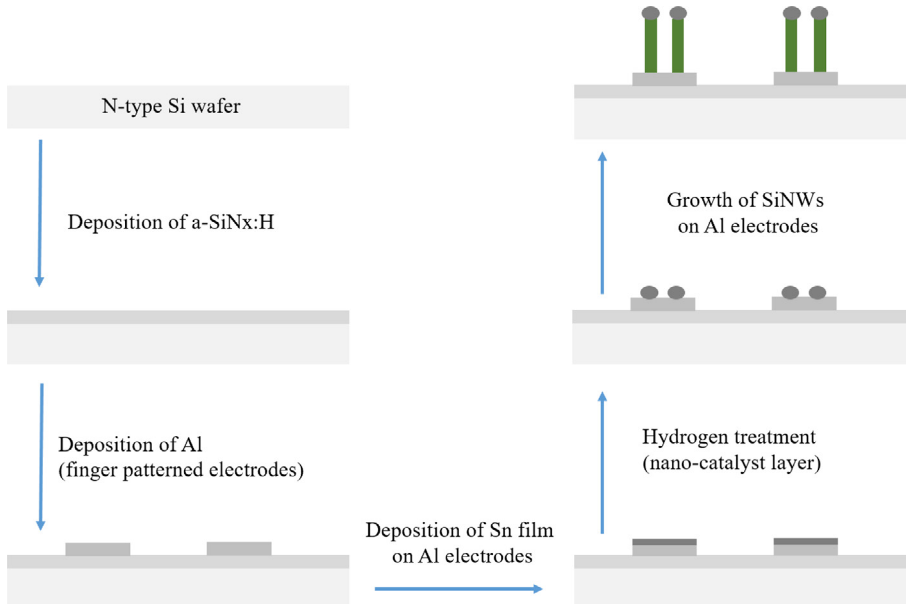

Fig. 1. Steps involved in the fabrication of on-chip SiNWs μ-SC.

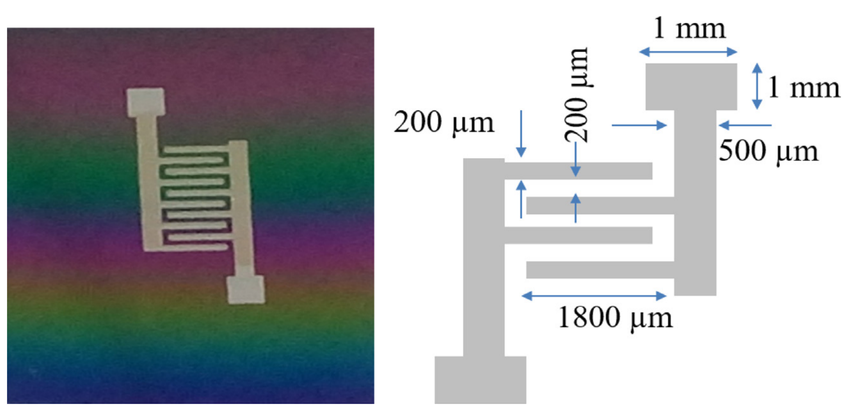

Fig. 2. Digital photograph of SiNWs based μ-SC and its dimensions.

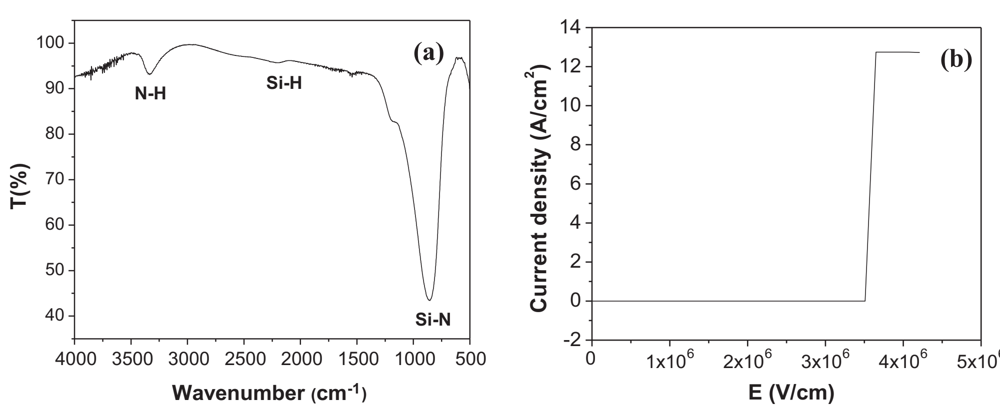

Fig. 3. FTIR spectra of the as-deposited a-SiNx:H film (a) and its I-V curve (b).

on finger-patterned Al current collector through the same metal mask to grow the SiNWs. To convert the Sn film into nano-particles (or nano-template), it was annealed in presence of atomic hydrogen generated by the heated filament in HWCVP chamber at a substrate temperature of 350 °C. The hydrogen was used to remove the Sn oxide layer from the nano-particles. SiNWs growth was performed by Vapor Liquid Solid (VLS) mechanism in the same chamber. To grow the SiNWs, the flow and the chamber pressure