Silicon nanowires and nanopillars arrays for lithium-ion battery and micro-battery: overview, challenges and perspectives

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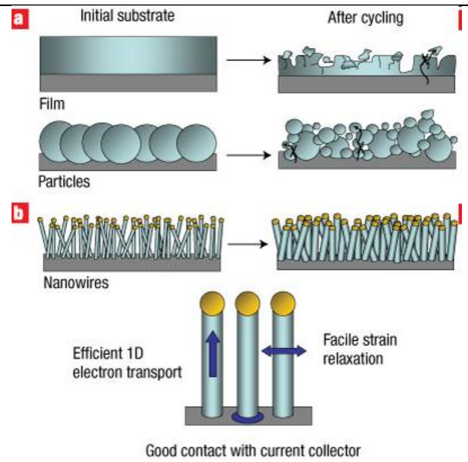
Nowadays, energy autonomy appears to be the main challenge for hybrid/electrical vehicles as well as nomadic electronic devices. Coin and rechargeable batteries remain the only available sources to supply such devices. The energy autonomy is a societal and critical issue and the nanotechnology could help the research community to improve the devices performances in particular in the field of lithium ion battery/micro-battery. A classical lithium ion storage device is composed of a positive electrode (mainly $LiCoO_2$), a lithium ion electrolyte (liquid or solid) and a negative electrode (graphite). The capacity of the graphite electrode is unfortunately limited to 372 mAh/g.

The silicon material appears to be a promising candidate for the negative electrode as it has the potential to be a host material for the lithium ion Li^+ with the highest reported specific capacity close to 4200 mAh/g. Unfortunately, the lithiation process (insertion of the lithium ion into the silicon crystal) occurring during the battery charging leads to a silicon's volume variation of 300 %. The high volume expansion of the silicon crystal remains the main cause of both the capacity fading and the pulverization of the fabricated battery. The lifetime of the lithium ion battery based on silicon material is then considerably reduced. Several research groups have developed novel negative electrode topologies using nanostructured silicon material in order to overcome the problem of the volume variation [1-6]. A negative electrode based on silicon material with an empty rate close to 50 % and allowing a volumetric expansion of the silicon crystal owing to the lithiation process is generally proposed. To obtain such empty electrodes, the nanotechnology seems to be a useful tool. Two different approaches could be investigated to produce silicon nanowires or nanopillars array. The bottom up way consists in the growth of silicon nanowires by Chemical Vapor Deposition (CVD) on stainless steel substrate according to the well known Vapor-Liquid-Solid (VLS) or Vapor-Solid (VS) processes. The 2nd path way (top down development) is based on the micromachining of the silicon material either by wet or dry etching [7-8].

This paper reports an overview of the silicon nanowires or nanopillars acting as a negative electrode of a lithium-ion battery or micro-battery. The bottom up (CVD synthesis) and top down (wet or dry etching) approaches will be compared. The potentialities of the silicon nanowires/nanopillars and their integration in a lithium-ion battery or micro-battery will be discussed. An original SiNPL micromachining processes using Deep Reactive Ion Etching and photolithography technologies will be presented. In the depicted process, the SiNPL array is obtained without electron beam nanolithography.



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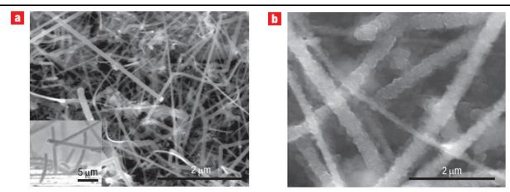

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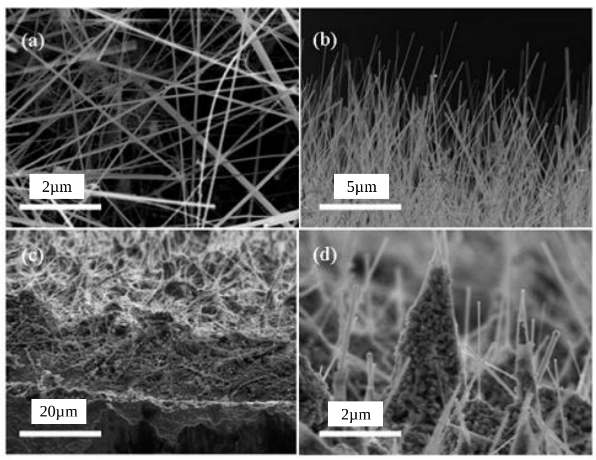

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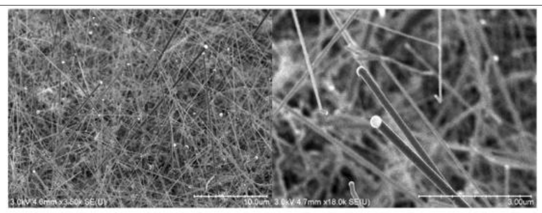
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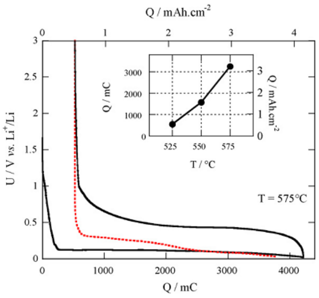
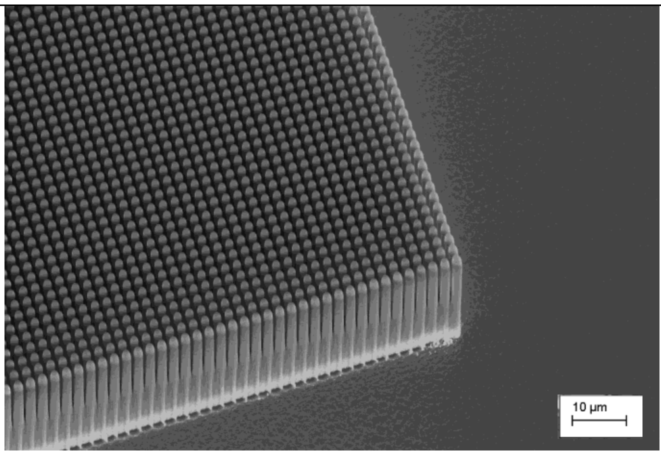
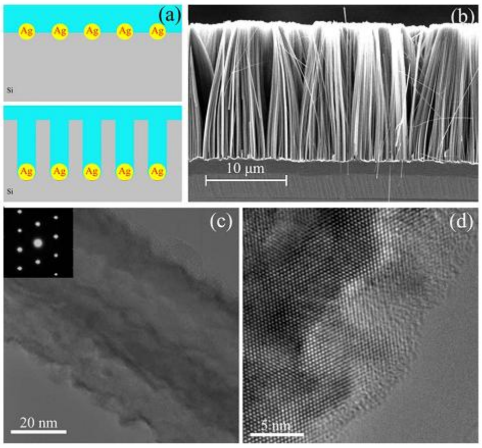


(e)

Fig. 1. Bottom up synthesis (Chemical Vapor Deposition) of silicon nanowires acting as a negative electrode of a lithium ion battery ((a), (b) et (c) Y. Cui *et al* [2, 3, 4, 6]) and (d), (e) Pereira *et al* [1, 5]



(a)



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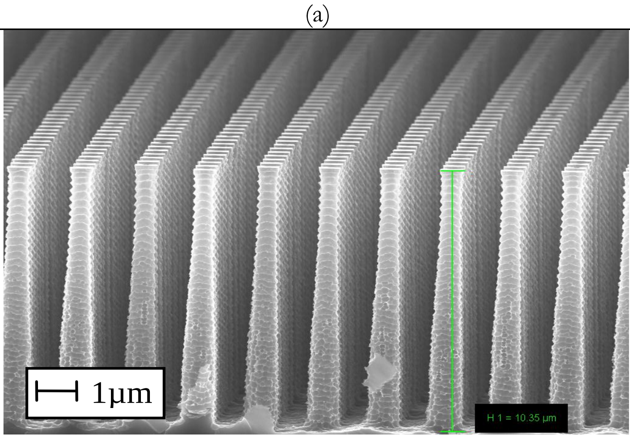

(c)

Fig. 2. Silicon nanopillar (SiNPL) array obtained by a top down approach [6-7]. This SiNPL array acts as the negative electrode of a lithium ion micro-battery [7] and is realized by Deep Reactive Ion Etching ((a) and (c)). The silicon nanowires reported in (b) are obtained by chemical wet etching [6].

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