The Use of Microtubule Proteins for the Manufacture of Nanowires

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ABSTRACT

Cell biology and nano-scale science share common goals of understanding and manipulating structures at the molecular level. The use of nature's proteins to help guide the assembly of inorganic materials is one emerging strategy for building new nano structures. Proteins of the cellular cytoskeleton, such as tubulin polymerizing into microtubules, have the favorable characteristics of linear modularity and reversible self-assembly. Here, I demonstrate the formation of metallic nanowires, which have been cast by utilizing the hollow lumen of the microtubule. I also provide strategies for arrangement of microtubule nanowires, and methods for generating diversity of co-axial and heterostructured microtubule nanowires.

KEYWORDS

Microtubule, Lumen, Nanowire

INTRODUCTION

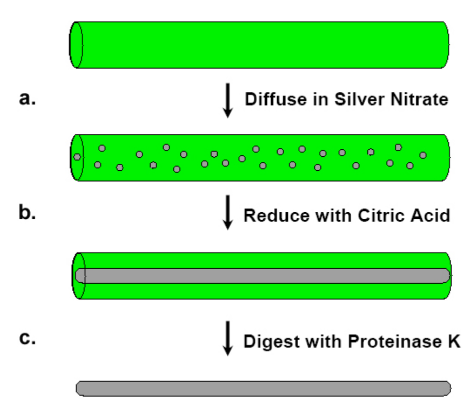
There has been growing interest in the formation of new molecular components built with a "bottoms-up" approach: small molecularly-precise parts coming together to become larger ordered complexes, all orchestrated by a series of controlled assembly events. Proteins have proven to be useful building templates for assembling metallic material, with such biologically-inspired examples as nanowires made from amyloid fibers [1] and peptide nanotubes [2].

The microtubule is a dynamic cytoskeletal polymer, made up of a hollow cylinder of alpha- and beta- tubulin heterodimer subunits [3]. Microtubules can be polymerized and stabilized by the anti-cancer drug taxol. The interior wall of the microtubule has been shown to be the site of taxol binding [4]. Although still unknown, a biological function for the hollow microtubule lumen was postulated to serve as a conduit for the transport of material [5]. Kinetics studies have shown the ability for taxol and for other molecules to diffuse inside microtubules [6, 7, 8]. With these biological and physical features of microtubules in mind, I sought to enhance the functionality of the microtubule lumen by using it to shape metallic material.

TECHNOLOGY

For the formation of metallic nanowires cast from microtubule lumens, I have used the following synthesis strategy (Fig. 1). Tubulin protein was polymerized into microtubules using taxol, followed by the diffusion (1a) of silver ions into the lumen, with a subsequent reduction (1b) of the silver ions into silver solid using citric acid. The microtubule protein templates were then optionally destroyed with proteinase k digestion (1c) and with heat.

Fig. 1: Microtubule Nanowire Synthesis Strategy



Metallic nanowires (data to be shown on presentation) resulting from the reaction were visualized directly with transmission electron microscopy, with no fixation and no staining. Only by using microtubules during the synthesis, silver metal was organized and assembled into long filamentous structures, with diameters consistent with the approximately 16 nm diameter of the microtubule lumen itself. This represents the first nanowire formed by filling up a naturally hollow protein polymer and allowing the inside dimensions to place a limit on the size of the resulting product.

IMPACT ANALYSIS

There is a need in the field of nano-scale science and technology for the manufacture of components built with molecular-level control. Exciting progress has been made in the science and applications in this field, with promising materials such as carbon nanotubes and nanowires.

However, important obstacles remain and must be addressed, before these nano-scale technologies can be implemented into large volume productions for useful devices in the future. In the field of nanowires, examples of challenges include: control of nanowire dimensions, placement and arrangement of nanowires, and the use of synthesis strategies less toxic to the environment.

Nanowires manufactured with the biological microtubule protein, may help address these challenges of nano-scale component production:

Control of Nanowire Dimensions: The interior of the microtubule lumen remains fairly constant at about 16 nm in diameter, a size reflecting the natural dimensions of microtubules consistently reproducible with each polymerization reaction of tubulin proteins into filaments. Nanowires cast within the lumen will conform within the dimensions of the surrounding protein template.

Placement and Arrangement of Nanowires: There is a rich variety of microtubule binding proteins that are well characterized in biology. These proteins with specific binding locations along the microtubule, may help guide and orient the microtubules and their associated nanowires, into desired locations. This arrangement strategy will be based on time-saving self-assembly and molecular recognition via proteins, with minimal user manipulation of individual nanowires.

More Environmentally Friendly Strategies: The synthesis reaction to manufacture microtubule nanowires is carried out under mild conditions using starting materials which are widely available and relatively safe to handle. Furthermore, from a social benefit point of view, environmentally-friendly user-optimized green chemistry can help jumpstart developing nations to be empowered with the toolsets for them to make contributions in nano-scale science and technology.

INNOVATION

Microtubule nanowire technology introduces the following innovation areas for the first time**:**

Microtubule Lumen Casting: The hollow lumen space within the microtubule cylinder is put to use, to shape and form nanowires that have dimensions molded by their surrounding protein templates.

Microtubule Nanowire Heterostructural Diversity: The alpha- and beta- tubulin protein units in the microtubule polymer can each be conjugated with different metals, forming a heterostructural nanowire which consists of regularly-alternating metals reflecting the alternating protein units.

Microtubule Co-Axial Nanowires: Nanowire material can be placed both inside the hollow lumen and on the outside of the wall of the microtubule protein template, creating a co-axial nanowire.

Guidance and Positioning Using Biology: Microtubules have a distinct polarity of a "plus end" and a "minus end", and the use of microtubule-binding proteins which specifically bind to these particular ends can be used to guide and effect placement of the microtubule and its associated nanowire.

DEVELOPMENT TIMELINE

I began to think about microtubule nanowire technology, after being inspired by the observation that toilet paper compressed into the hollow cardboard cylinder of toilet paper rolls, produces solid masses of tissue paper that conform to the universal standard diameter of the cardboard paper roll. This inspiration combined with my experiences with video microscopic imaging of microtubule dynamics in living cells, prompted me to explore the possibility of using the microtubule protein polymer for engineering purposes. After my demonstrating proof-of-concept on October 22, 2004, work is continuing in the area of microtubule nanowire arrangement and generation of nanowire diversity. Starting with my primary training in the area of cell biology and in medicine, I am excited about expanding the project and integrating the role of nano-scale materials science into these fields, to build multi-disciplinary collaborations between academia and industry. Potential application areas are centered at the junction of biology and electronics, such as nano-scale components manufacturing and biological sensors.

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