Preparation of semi-1D transition metal oxide structures.

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ABSTRACT

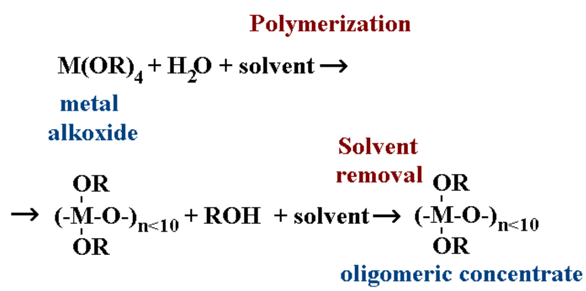
In this work we demonstrate the applicability of high viscous oligomeric alkoxide concentrates in fabrication of technologically interesting structures like miniature diameter fibers, needles and linear surface structures. The approach is a cost-effective and simple method for preparing nanostructured materials as it utilizes low-cost precursor materials (metal alkoxides) combined with low-tech processing (tape casting, fibers pulling, aging and baking). We show that the method enables to obtain fibers close to a micron in diameter and needles with tip radii down to 15 nm. Also, a method to cast narrow oxide linear structures onto a substrate is described.

Keywords: fibres, tape casting, SPM tips, sol-gel, alkoxides

1 INTRODUCTION

Preparation of (sub)micron transparent surface structures and fibers is one of the central questions in a wide variety of optical and optoelectronic applications. The highest resolution is achieved using e-beam and focused ion beam lithography (resolution down to some nm-s), followed by different optical lithography methods [1]. Apparently, these methods enable to pattern a substrate of interest with desired structures like holes and lines, but self-standing structures like fibers cannot be easily made by these means. Predominantly, these techniques appear to be costly for large-scale production. A cost-effective alternative for conventional lithography processes – soft lithography – was introduced nearly a decade ago [1] and its development is still expanding because it does not sacrifice any of the useful features inherent to other forms of lithography.

In our earlier works we have shown that high viscosity transition metal alkoxide concentrates can be used for making ultra-sharp tips [2,3] applicable as scanning tunneling and photon imaging microscopy probes [1], and also for making thin and narrow stripes on a substrate [1]. The approach is based on well-known sol-gel processing, where monomeric transition metal alkoxide is polymerized, followed by extraction of the solvent and water, remaining highly viscous polymer concentrate:



(1)

The material can be readily shaped to aforementioned nanometric structures at room temperature and then transformed to solid oxide state as a result of aging and baking. In this paper we primarily refer to the possible (nano)technological applications of highly viscous alkoxide concentrates. The approach is suitable for not only micropatterning, but also for making self-standing nanometric structures: fibers and needles (Figure 1). Because of its low-tech nature and low cost the method may hold valuable impact on relevant technologies in the future.

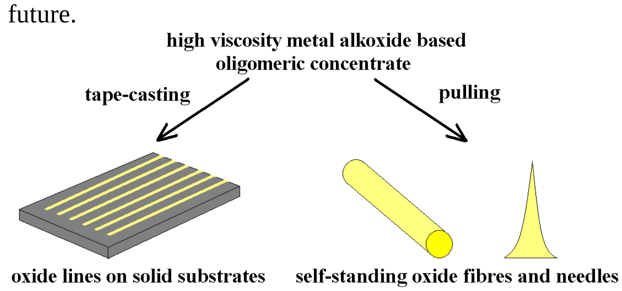


Figure 1. Schematic illustration of the different applications of high viscosity alkoxide concentrates.

2 FIBERS, NEEDELS AND MICROPATTERNS OF TRANSITION METAL OXIDES

Starting with a neat liquid transition metal alkoxides (transition metal: Ti, Sn) the precursor material is made simply by addition of water in an appropriate solvent [3]. As a result, the alkoxide polymerizes (see eq. (1)) to the extent of up to ten monomers. The remaining alcohol and solvent are then extracted from the formed oligomeric mass, and the basic material for fabrication of nanostructures is obtained. The oligomeric concentrate is a highly viscous mass, which can only be stored in dry atmosphere. If introduced to humid air the material continues to polymerize via cross-linking the individual oligomer molecules near to the exposed surface, leading to solidification of the surface. Eventually, the material becomes completely solid, but still containing some organics and water. These can be removed by heating the material to a sufficient temperature, depending on the type of the oxide and desired degree of crystallinity. We use the described procedures for making different micro- and nanostructures.

Fibers and needles are made by pulling the concentrate with a stick [2,3]. Here, the outcome depends on the viscosity of the concentrate, pulling speed and humidity of the surrounding atmosphere [3]. By carefully optimizing the parameters nanometrically sharp needles (Figure 2) and ultra-narrow fibers (Figure 3) can be drawn. As transition metal oxides are typically transparent and can be readily made conductive via addition of appropriate dopants the structures may have many practical applications, e.g. probes for simultaneous STM and photon imaging [4] and others.

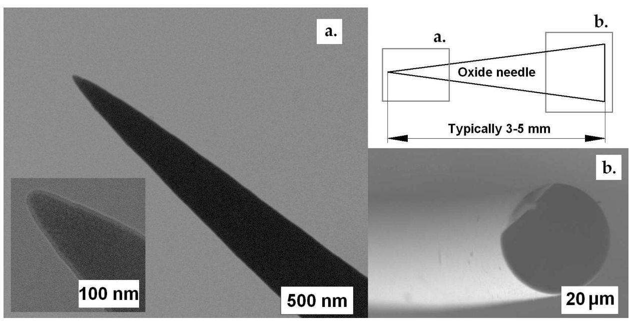


Figure 2. Nanometrically sharp oxide needles (SnO_2).

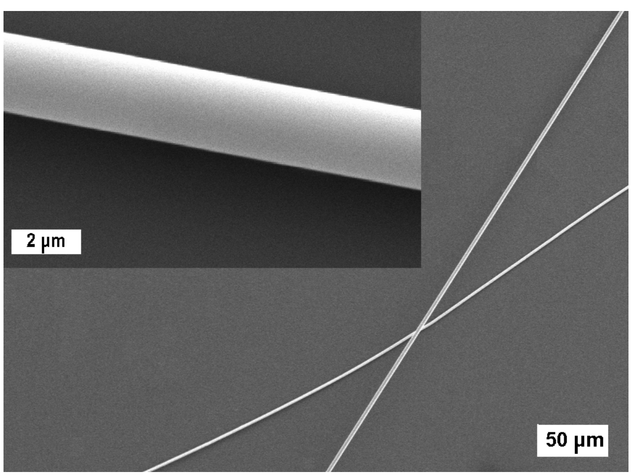


Figure 3. Microscopic oxide fibers (TiO_2). The fibers can be drawn up to several cm-s in length.

Nanopatterning is performed by tape casting the precursor to a substrate using an appropriate blade. We prepared the structured blade from a cleaved silicon monocrystal using conventional wet etching technique [5]. The surface typically does not require any special treatment and ordinary glass can readily be applied. Figure 4 shows an example of obtained structures.

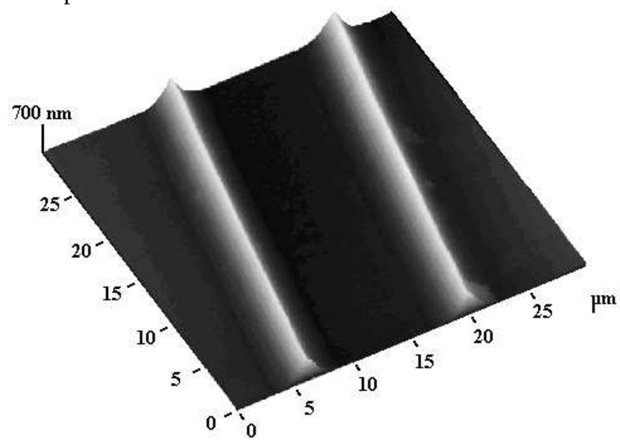


Figure 4. A fragment of a tape casted microstructured film prepared using a blade with triangular cross-section grooves.

The cross-section of the structures is directly determined by the shape of the grooves on the blade, as can be seen in Figure 4. There is no fundamental limit on the lengths of the structures and tens of square centimeters of patterned areas have already been demonstrated in practice. Furthermore, the lines can intentionally be made nonlinear and even applied to uneven substrates.

The described structures can be easily doped in order to modify the useful properties of the material such as conductivity, hardness, fluorescence and others.

3 CONCLUSIONS

Transition metal alkoxide concentrates are promising materials for fabrication of nanometric fibers, needles and micropatterns because of low cost and simplicity of their production. The method is focusing more on the lower resolution and flexible production of micro- and nanostructures and is thus complimentary to the conventional lithographic methods. Transition metal oxide nanostructures have useful practical applications in nano-optics, -electronics and –optoelectronics, since optically transparent and conductive and fluorescent materials can be fabricated.

ACKNOWLEDGEMENTS

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