Preparation of Transparent Electrodes Based on CNT-s Doped Metal Oxides

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ABSTRACT

In present work we demonstrate preparation of transparent and electrically conductive electrodes suitable for utilization in solar cells and as different displays. Materials as fibers and films are readily obtained by using inexpensive chemical method where processing transition metal alkoxides together with single-wall carbon nanotubes (SWCNT-s) leads to metal oxide/SWCNT composite materials. Since transition metal oxide/CNT hybrid materials have good characteristics of both substances, it would be stimulating subject for industry.

Keywords: *transparent electrodes, SWCNT composites, sol-gel, alkoxides*

1 INTODUCTION

In recent years electrically conductive and transparent electrodes have been among the most important issues in optoelectronics. The field of applications of these electrodes varies from solar cells to different displays. As increased need for transparent electrode material indium tin oxide (ITO) has raised the price of indium around 10 times since the year 2000 [1], it has set the search for alternative materials into focus.

Carbon nanotubes (CNT-s) are widely known for extremely good mechanical and electrical properties and are applicable in a wide optical range [2]. For that reason, CNT-s have been used as dopants to improve electrical and mechanical characteristics of different transparent materials in order to create new electrode materials [3]. Being the cheapest, the main materials tested as matrixes are different organic polymers [3]. Still, these materials have some drawbacks compared to ITO, like lower chemical and mechanical stability.

To overcome these problems we have started studies to design electrodes based on high refractive index transparent metal oxides like TiO_2 and SnO_2, which are among the most stable compounds. As these materials also have high hardness, they are often used as protective layers [4].

We have shown in our earlier works that it is possible to prepare self-standing oxide fibers and films from high viscosity transition metal alkoxides [5]. These oxide structures are obtained by well-known, relatively simple and cost-effective sol-gel procedure. Method is based on oligomeric concentrates, which are obtained from neat metal alkoxides by addition of water, followed by removal of the solvent. The concentrates are highly viscous materials that can be transformed to desired shapes (fibers, films, powders etc.) at room temperature by appropriate combination of mechanical and chemical treatments (Fig. 1.).

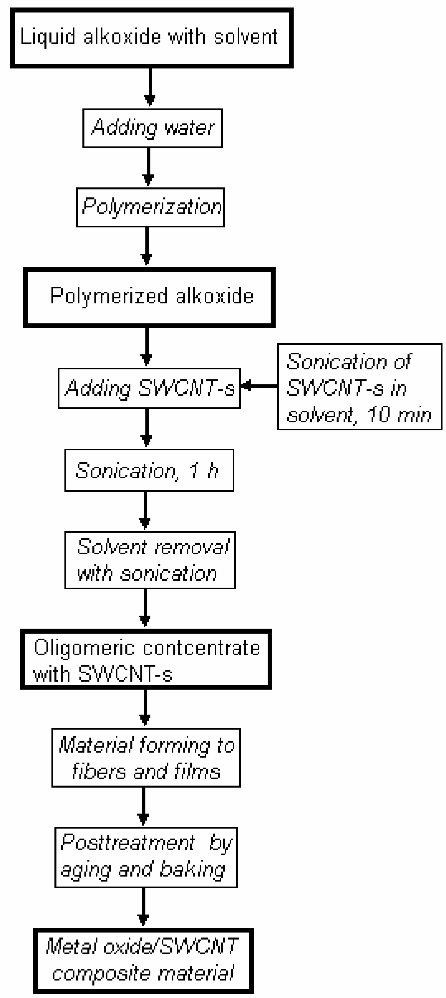

Figure 1. Preparation of CNT-e composite materials by sol-gel method.

In current work we demonstrate the preparation of transparent electrodes as a result of abovementioned treatment steps. Due to the simplicity of the method such electrodes could easily be introduced into the industrial production.

2 ELECTRICALLY CONDUCTIVE AND TRANSPARENT ELECTRODES

As mentioned above, preparation of electrodes is based on sol-gel method [5], [6]. Initially neat liquid transition metal alkoxide (transition metal: Ti, Sn) is polymerized by adding water in suitable solvent. Pre-sonicated single-walled carbon nanotubes (SWCNT-s) in solvent are then introduced into the polymerized alkoxide. Sonication is needed to attain homogeneous dispersion of nanotubes in solution and afterwards in polymerized alkoxide [7]. Before extraction of solvent and alcohol, material is processed in ultrasonic bath for approximately one hour to assure uniform medium. Obtained oligomeric concentrate with SWCNT-s continues to polymerize via cross-linking when introduced to humid air and can only be stored in dry atmosphere. Material will polymerize in humid environment until it becomes completely solid, containing still some organics and water.

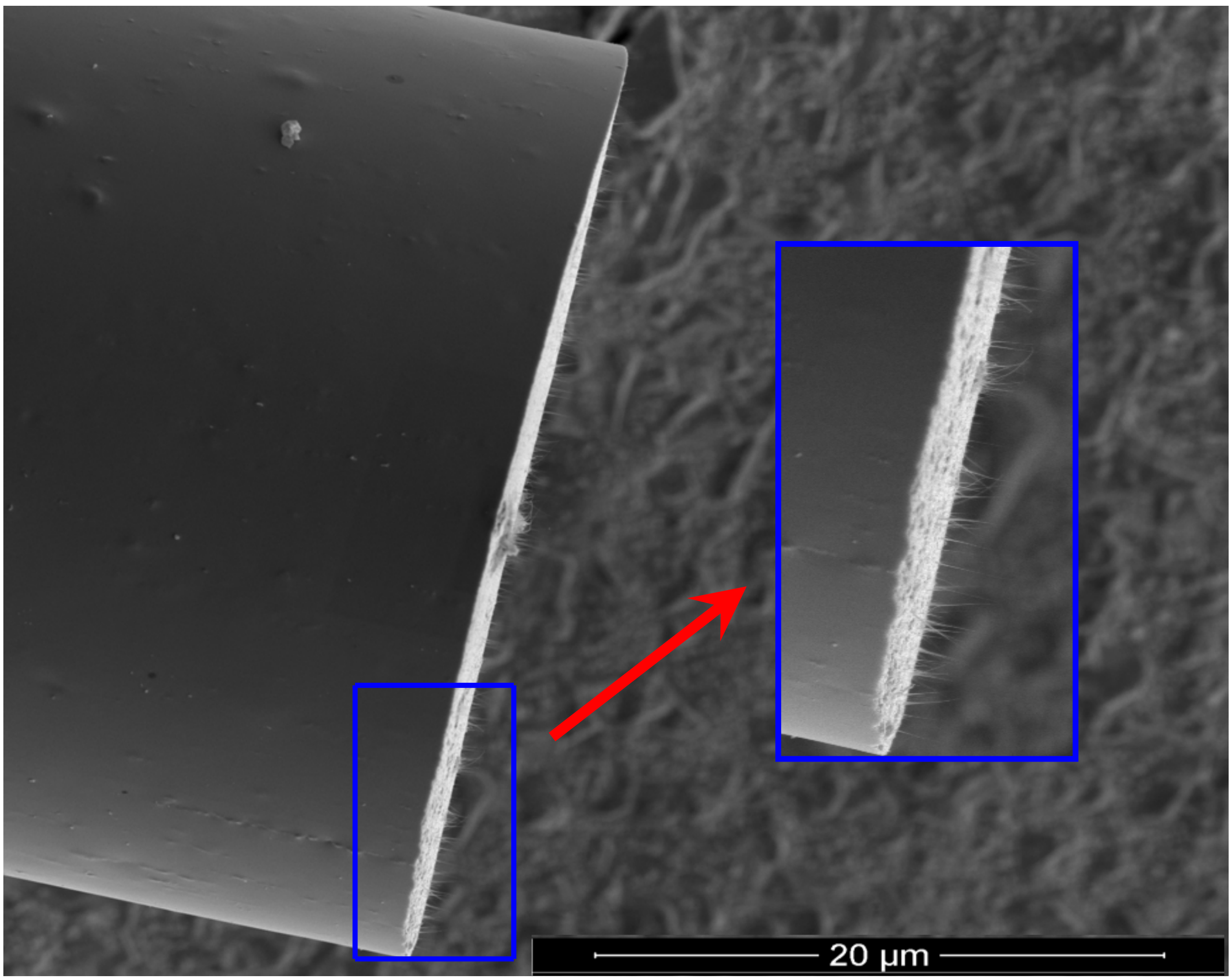

Figure 2. SEM images of a CNT-doped SnO_2 fiber. The fiber was mechanically broken prior to imaging in order to reveal the doped CNT-s. It can be seen that CNT-s are oriented along the axis of the fiber.

Electrodes as fibers are formed by pulling oligomeric mass in humid air [5], [6]. Dimensions of the fibers depend greatly on viscosity of the precursor material, humidity of the surrounding atmosphere, pulling speed and on nanotube aggregates remained in the matrix after sonication. Films are prepared by spin-coating or dip-coating.

SEM analyzes revealed that orientation of the nanotubes was anisotropic with a maximum alongside axis of the fiber (Figure 2). This could be explained by axial forces acting on nanotubes when polymerized alkoxide is drawn (Figure 3.).

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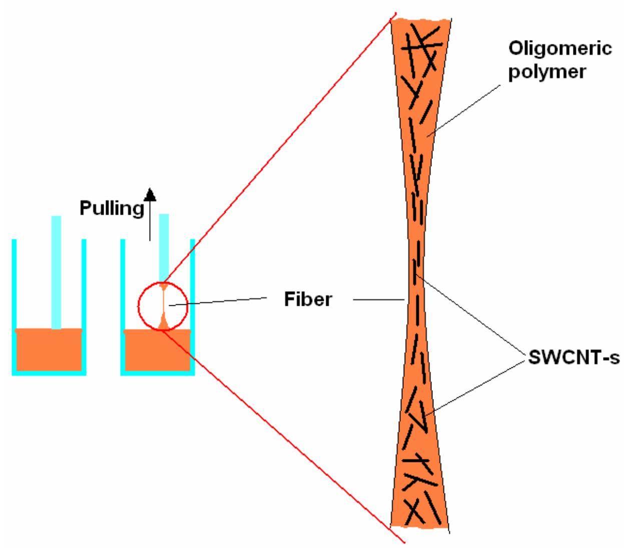

Figure 3. Fiber pulling process is orienting CNT-s.

After baking to 340 °C in air, dense oxide ceramics, doped by aligned nanotubes, were achieved in shape of fibers or films. Heating was needed to remove organics and water still in material after polymerization. Baking temperature was selected so that carbon nanotubes would not oxidize [8] and other organics could be removed as much as possible.

Fiber electrodes with diameters greater than 1,5 mm turned opaque as a result of heating, because organic remnants could not emerge from inside. Smaller than 1,5 mm strands remained on visual observation as transparent and were up to 25 mm long (Figure 4).

Figure 4. Electrically conductive and transparent tin(IV)oxide electrodes doped by SWCNT-s and with a diameter from 40 to 50 μm.

Electrodes electrical conductivities were measured by 4-point method. Maximum conductivity of 500 S/m was measured on fibres doped by 0,1 wt% SWCNT. It was also noted that fibers heated up to 400 °C, experienced a drop of conductivity down to 0,00015 S/m. This was in accordance with prior knowledge from thermogravimetric analysis [8], which states that all SWCNT-s should be oxidized at this temperature.

3 CONCLUSIONS

Current study proves that oxide/CNT composites films and fibers are potential materials for transparent electrodes applications. As transition oxides preserve good chemical and mechanical properties, these materials are promising in utilization as protective layers. Our results prove that SWCNT-doping significantly improves the conductivity of the fiber electrodes (up to 500 S/m).

ACKNOWLEDGEMENTS

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