Fabrication of CuO nanofibers via the plasma decomposition of Cu(OH)₂

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A B S T R A C T
The production of CuO nanofibers is a challenge. In this work, a novel, rapid and easy fabrication method for CuO nanofibers is reported. The nanofibers were prepared from the decomposition of Cu(OH)₂ using a dielectric-barrier discharge plasma initiated at ambient conditions. The diameter of the CuO nanofibers varied from about 30 nm to 100 nm, whereas the length was as long as 1300 nm. X-ray diffraction analyses showed the nanofibers possess a monoclinic CuO structure.

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1. Introduction
Copper oxide (CuO) nanoparticles have been extensively investigated for use in semiconductors, catalysts, gas sensors, lithium ion electrode materials, field emission emitters and many other areas. Methods for the synthesis of CuO nanoparticles include thermal decomposition [1], direct oxidation of copper-containing substrates [2], microwave irradiation or microwave heating [3–6], a chemical deposition method [7], wet-chemical methods [8–11], sonochemical preparation [12], and self-catalytic growth [13].

Recently, fabrication of CuO nanoparticles using various plasmas has also received attention [14–17]. A plasma is a substance in which part of the atoms or molecules are highly ionized. If sufficient energy is added to a gas or gas mixture, a plasma can be generated. Depending on the energy level, plasmas are usually classified as either high temperature plasmas or low temperature plasmas which includes thermal plasmas and cold plasmas. High temperature plasmas are normally used for nuclear applications. Low temperature plasmas are important for the syntheses and processing of materials. A thermal plasma is a plasma in which almost all its components are at thermal equilibrium. However, a cold plasma is different. The electrons in a cold plasma can reach temperatures of 10,000–100,000 K, while the gas temperature can remain as low as room temperature. The high temperature of the electrons determines the unusual chemistry of cold plasmas. Cold plasmas differ in the way the plasma is generated, the applied pressure, and the electrode geometry. Different types of cold plasmas include glow discharge, silent discharge (or dielectric barrier discharge) and radio frequency (RF) discharge [18]. Both cold and thermal plasmas can be easily applied to the production of CuO nanoparticles [14–17]. The advantage of fabricating CuO nanoparticles using plasmas is that the use of complex reaction steps, long time periods and/or hazardous chemicals becomes unnecessary.

Although many methods can effectively produce CuO nanoparticles, this fabrication of CuO nanofibers still remains a challenge. In this work, a dielectric-barrier discharge (DBD) plasma was applied to the fabrication of CuO nanofibers from Cu(OH)₂.

2. Experimental and setup
A DBD plasma is a cold plasma phenomena, operated at ambient conditions. They are different from other plasma phenomena, because one or both of the electrodes are covered by a dielectric-barrier material, like quartz or a ceramic material. The DBD reactor used in this investigation is shown in Fig. 1. The high voltage electrode is a steel plate attached to the inner surface of a quartz plate with a thickness of 2 mm. Another steel plate is also covered by a quartz plate with the same thickness and serves as the ground electrode. The diameter of the quartz plate was 60 mm, whereas it was 50 mm for the steel plate. The width of the discharge gap was 14 mm.

A high voltage generator (CTP-2000 K; Corona Laboratory, Nanjing, China) supplied a voltage with a sinusoidal waveform at a frequency of about 25 kHz. The voltage and current were measured using a digital oscilloscope (Agilent DS06052A) with a high voltage probe and a current transformer built into the high voltage generator. The largest...
applied voltage measured was 18.1 kV, whereas the input power was 134.2 W.

To fabricate the CuO nanofibers, the Cu(OH)\(_2\) powder (purity >96%; obtained commercially from Tianjin Wen Da Xi Gui Reagent Plant) was placed on the quartz plate in the gap of the DBD reactor. Each DBD decomposition operation was performed for 3 min and the operation was repeated three times for a total decomposition time of 9 min. Between operations, the sample was manually stirred. Fig. 2 shows a photograph of the DBD plasma during the fabrication. In order to study the thermal effect, Infrared (IR) imaging was used to measure the temperature of the DBD reactor. The IR image was taken with an IR camera (Ircon, USA).

X-ray diffraction (XRD) analysis was performed with a Rigaku D/MAX-2500 V/PC diffractometer with Cu K\(_\alpha\) radiation (\(\lambda=0.154178\) nm) at a scanning speed of 4°/min. Scanning electron microscopy (SEM) images were recorded with an XL30ESEM system.

3. Results and discussion

Fig. 3 shows an IR image of the quartz plate, taken immediately after the DBD decomposition was performed. According to the temperature measurement, the heating effect of the DBD plasma is not significant. The average decomposition rate under the influence of the DBD plasma is 2.17 times higher than that of thermal decomposition (at 180 °C). The average decomposition rate is obtained from the total mass lost divided by the time that the mass of the sample remains stable with no further decomposition observed. Further kinetic analyses will be reported in future work.

Fig. 4 shows a SEM image of the CuO fibers obtained from a DBD decomposition. The CuO nanofibers are as long as 1.3 µm, and have diameters from about 30 to 100 nm. Fig. 5 shows the XRD pattern of the CuO nanofibers formed from the decomposition of Cu(OH)\(_2\) using a DBD plasma. The XRD patterns indicate the formation of monoclinic CuO structures.

4. Conclusion

In this work, we confirm a DBD plasma can be effectively applied for the fabrication of CuO nanofibers. The decomposition of Cu(OH)\(_2\) under a DBD plasma is rapid and easy to operate. The present study not only provides a new method to fabricate CuO nanofibers but could also be applied to the fabrication of other metal oxide nanofibers or nanoparticles.

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