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Thesis outline

Title

Formation and Applications of SiC Nanowires Synthesized by Thermal Evaporation Method

Abstract

β-SiC/SiO_2 core-shell nanowires (SiCNWs) were synthesized by thermal evaporation method using pre-oxidized silicon powder and methane gas as precursors. The exhaust gases during the SiCNWs synthesis process were examined by gas chromatography and the photographs of growth activity of SiCNWs inside the furnace were captured. CO gas was detected during the active formation of SiCNWs. It was clarified that CO gas was one of the byproducts from SiCNWs synthesis process, and the formation of SiCNWs was discussed based on the oxide-assisted-growth mechanism. Alumina matrix composite containing very small amount of SiCNWs (0.2 wt%) were prepared by hot-pressing. The thermal conductivity of the composite was improved about 45% from that of the monolithic alumina. Furthermore, the alignment of SiCNWs in alumina matrix composites was observed in the specimens prepared by slip-casting under a strong magnetic fields (12 T). It was firstly found that β-SiC (cubic crystal) with a presence of stacking faults was able to align parallel to the magnetic field. Specimens were sintered by SPS or milliwave sintering and their mechanical properties were evaluated.

Chapter 1 - Introduction

Background and objective of this research are mentioned in this chapter. It is well-known that SiC nanowires have excellent properties, such as high mechanical strength, high thermal conductivity and high thermal stability, thus SiCNWs are attractive materials for application in nano-electronic devices and reinforcement of composite materials. Thermal eaporation method is an effective and un-conplex way to synthesize relatively high yeild of SiCNWs without addition of catalyst. However, the formation mechanism of SiCNWs synthesized by thermal evaporation method is still unclear and the applications of SiCNWs is still limited. Therefore, research on the growth mechanism of SiCNWs, including study on their applications are meaningful. The objectives of this research are as follows; (1) Confirm

synthesis process of SiCNWs and clarify the formation mechanism, (2) Clarify the effects of SiCNWs addition on the properties of alumina ceramics, (3) Clarify the effects of magnetic field on the alignment of SiCNWs in alumina matrix composite.

Chapter 2 - Synthesis, Characterization and Formation Mechanism of SiC Nanowires

A simple thermal evaporation of silicon powders during decomposition of CH_4 in a mullite tube furnace was used to synthesize SiCNWs. Large amount of long SiCNWs with smooth-surface were obtained and their average diameters were 45 nm and up to 1 mm long. These nanowires had a single crystal β-SiC core and amorphous SiO_2 shell. During the formation of SiCNWs in this process, exhaust gases were analyzed by gas chromatography and the growth activity of SiCNWs was captured by the digital camera. CO gas was detected from the exhaust gases of the production system only when SiCNWs were quickly growing. From these experimental results, it was confirmed that CO gas was one of the main byproduct of the SiCNWs formation. The formation reaction of SiCNWs should be:

$$3SiO(g) + 3C(s) \rightarrow 2SiC(s) + SiO_2(s) + CO(g)$$

The SiCNWs formation was discussed by oxide-assisted-growth mechanism. Moreover, the oxygen content in the starting silicon powder was also important, it had to be about 20 wt% to obtained highest amount of SiC nanowires in this synthesis process.

Chapter 3 - Effects of β-SiC/SiO_2 Core-Shell Nanowires as an Adding Material on the Properties of Alumina Matrix Composite

Alumina matrix composites reinforced with very small amount of SiCNWs prepared by hot-pressing was characterized. Alumina matrix specimens that contained SiC nanopowder were prepared for comparison. Grain sizes of SiC-added alumina specimens were one fifth of that of the monolithic one. Vickers hardness of both SiC nanowires and SiC nanopowder-added specimens were higher than monolithic alumina around 10%. Fracture toughness decreased ~15% both in SiC nanowires and SiC nanopowder-contained specimens. Thermal conductivity of specimens was increased with increasing the amount of SiCNWs. It was found out that the SiCNW is a better additive for increasing thermal conductivity of the alumina matrix composites, than the SiC nanopowder due to its wire shape. As a result,

adding 0.2 wt% of the SiCNWs increased the thermal conductivity of alumina by as much as 45%. From these results, it was clarified that only small amount of nano-sized SiC as an additive material has a large effect on properties of alumina matrix composite.

Chapter 4 - Effects of Strong Magnetic Field on the Alignment of SiC Nanowires in Alumina Matrix Composites

SiCNWs were successfully dispersed in water by ultrasonic homogenizer and the zeta potential of SiCNWs in water were analyzed. Dense alumina matrix composites containing 1 wt% SiCNWs were prepared by colloidal processing, consolidated by slip-casting in a strong magnetic field (12 T) and sintered by SPS or milliwave sintering. In general, it is difficult to control the orientation of the material with cubic crystal structure by a magnetic field under normal circumstance. However, it was found that the alignment of SiCNWs was mainly dominated by the direction of magnetic field. SiCNWs were aligned parallel to the direction of magnetic field due to the anisotropic of magnetic susceptibility cause by the stacking faults. And some of SiCNWs were aligned perpendicular to the slip-casting direction due to the capillary force and pressure during sintering. Sinterability of the alumina matrix composite containing SiCNWs was improved by aligned SiCNWs in horizontal direction to the pressing direction. The Vickers hardness and elastic modulus of the slip-casted specimen in the horizontal direction were higher than those of the specimen slip-casted without the magnetic field. Furthermore, milliwave sintering method was an effective method to densify alumina matrix composites containing SiCNWs at lower temperature than SPS.

Chapter 5 - Summary

Finally, this chapter summarized the important results and findings in this thesis.