Applied Thermal Engineering 94 (2016) 350–354

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Silicon carbide nanowires suspensions with high thermal transport properties

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HIGHLIGHTS

- The ethylene glycol suspensions containing SiC nanowires were prepared.
- The thermal conductivity of SiC/EG suspensions is significantly improved.
- The large aspect ratio of SiC nanowires favors thermal conductivity enhancement.
- The experimental data are in reasonable agreement with Hamilton–Crosser model.

ARTICLE INFO

Article history:
Received 28 August 2015
Accepted 24 October 2015
Available online 2 November 2015

Keywords:
Silicon carbide (SiC) nanowires
Suspensions
Large aspect ratio
Thermal conductivity

ABSTRACT

Nanofluids have a broad prospect for thermal management applications in many fields. In this paper, ethylene glycol (EG) suspensions containing silicon carbide (SiC) nanowires were prepared by mechanical mixing. The average thermal conductivity of suspensions with SiC nanowires is greatly improved compared with that of pure EG, and it increases with the volume fraction of SiC nanowires. When the SiC loading is 5.0 vol.%, the thermal conductivity of the suspension was 0.443W/mK, increasing 67.2% with respect to pure EG. There is no obvious temperature dependency for the thermal conductivity enhancement ratio. These experimental results are in reasonable agreement with predicted values of Hamilton–Crosser model. The research confirms that the shape factor of SiC has a critical effect on the effective thermal conductivity of suspensions. Meanwhile, it validates that the SiC nanowires have stronger ability to enhance thermal conductivity of suspensions than the other shapes. It is due to the large aspect ratio of SiC nanowires, which can easily form bridges between them, known as conductive network. The formation of random bridges or networks from conductive particles facilitates phonon transfer, leading to high thermal conductivity.

1. Introduction

In order to improve the thermal conductivity of heat transfer fluids, the most effective approach is using thermal conductive particles as additives, including metal, metal oxide, graphite and carbon nanotubes, etc. However, such suspensions containing particles with size ranging from micrometers to millimeters are ordinarily unstable and prone to clogging systems with small channels [1,2]. Choi and Eastman [3] first proposed the concept of nanofluid in 1995; that is, in a certain way, the proportion of nano-sized metal or metal oxide particles is added to a liquid to form a class of new heat stable fluid with relatively high thermal conductivity. The rapid development of nanotechnology has permitted uniformly stable nanofluids to be a reality. Thus far, nanofluids, used as novel heat transfer working fluids, have broad application prospects in heat transfer fields, such as power generation, chemical production, manufacturing, transportation, and many other facets of modern life [4–8].

In the past two decades, many researchers [4–7] have demonstrated that nanofluids, containing a small amount of metal or nonmetal nanoparticles, exhibit substantially enhanced thermal conductivities in comparison to those of the base fluids. The nanosized particles, such as Cu [9,10], Al_2O_3 [11], CuO [12], MgO [13], ZnO [14] CNT [15] and graphene [16,17], have been used as fillers to improve the thermal conductivity of nanofluids based on water, glycol or oil. In essence, nanofluid is a mixture of base fluid and nanoparticles. According to the theories of the effective thermal conductivity of mixtures, such as the Maxwell model [18], Hamilton and Crosser model [19], and Davis model [20], the size, shape and intrinsic thermal conductivity of nanoparticles have a great influence on the thermal conductivity enhancement of nanofluids.

In this paper, silicon carbide (SiC) nanowires are selected to prepare nanofluids due to their high thermal conductivity and large aspect ratio, which is favorable to enhance the effective thermal conductivity. Timofeeva et al. [21] investigated the effect of average

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http://dx.doi.org/10.1016/j.applthermaleng.2015.10.116
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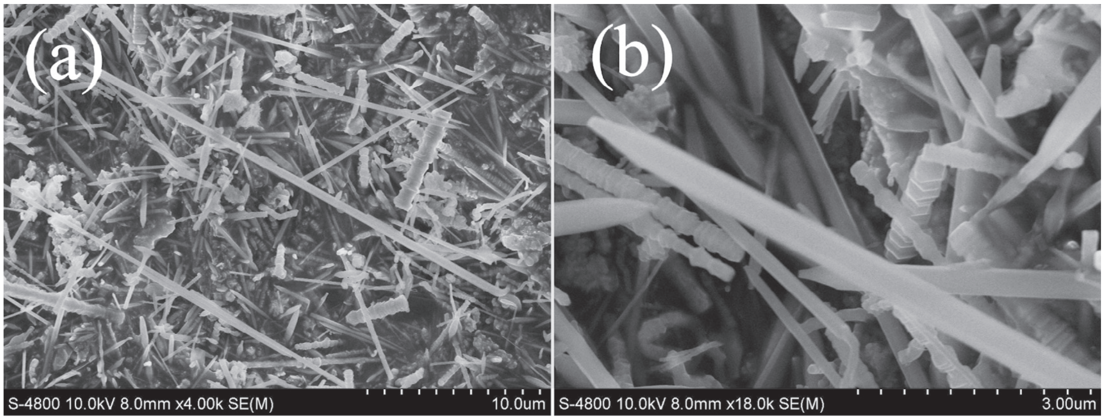

Fig. 1. SEM images of SiC nanowires (a) at low magnification and (b) at high magnification.

particle size on basic macroscopic properties and heat transfer performance of α-SiC/water nanofluids. It suggested that nanofluids with larger particles exhibit higher thermal conductivity and lower viscosity because of the smaller solid/liquid interfacial area of larger particles. They also [22] investigated base fluid and temperature effects on the heat transfer efficiency of SiC in ethylene glycol (EG)/ H_2O and H_2O nanofluids. Adding SiC nanoparticles to an EG/H_2O mixture could significantly improve the cooling efficiency. Yu et al. [23] reported SiC/water nanofluid with 50–60% increase of heat transfer coefficient above the base fluid when compared on the basis of constant Reynolds number. Manna et al. [24], Hosseini et al. [25] and Xie et al. [26,27] also investigated the effect factors on the thermal conductivity of nanofluids containing SiC, and their results indicated significant increase in thermal conductivity.

To further investigate the effects of shape and size of SiC on the thermal conductivity of suspensions, the SiC nanowires with high aspect ratio were added to EG to prepare SiC-based suspensions. The experimental thermal conductivity data were compared with the results of suspensions containing SiC nanoparticles with other shapes and expected values of theoretical model.

2. Experimental

The SiC nanowires provided by Changsha Sinet Advanced Materials Co., Ltd., China, were used without further treatment. The morphology and crystal structure of SiC nanowires were characterized by field emission scanning scope (SEM) (S4800, Hitachi, Japan) and X-ray diffractometer (XRD) (D8 Advance, Bruker, Germany), respectively. The EG with analytical grade was purchased from Sinopharm Chemical Reagent Co., Ltd., Shanghai, China, and was used without further purification. The suspensions with different loading of SiC nanowires were prepared by mechanical mixing SiC nanowires with EG using a planetary mixer/deaerator (Mazerustar KK-250S, Kurabo, Japan).

The effective thermal conductivity of suspensions was measured using a thermal conductivity analyzer (C-Therm TCi, C-Therm Technologies Ltd., Canada), which is based upon the modified transient plane source principle. In order to keep the temperature constant, the test system including test samples was placed in constant temperature and humidity incubator (Shanghai Boxun Industry & Commerce Co., Ltd Medical Equipment Factory). The accuracy of temperature control in the incubator is ± 1 °C. All the thermal conductivity measurements of the samples in the experiments were repeated at least five times to ascertain the accuracy of the experimental results.

3. Results and discussion

3.1. Characterization of SiC nanowires

The shape and size of SiC nanowires were observed by field emission scanning electron microscope, as shown in Fig. 1. As seen in Fig. 1a and b, the SiC exhibits long straight wire-like or short bamboo-like structures. The surface of long straight wire-like SiC is very smooth, while the short bamboo-like structure resulted from corrosion of hydrofluoric acid in purification process. The diameter of SiC nanowires varies over a wide range from 0.2 to 1 µm and the length is 3–40 µm.

The crystallinity and crystal phases of the sample were characterized using X-ray diffractometer. Fig. 2 shows the XRD pattern of the SiC nanowires, which shows six obvious and sharp diffraction peaks at 2θ = 33.6°, 35.8°, 41.4°, 60.0°, 71.8° and 75.5°, respectively. Among these peaks, the peaks indexed as (111), (200), (220), (311), and (222) correspond to the different facets of face-centered cubic β-SiC (JCPDS 74–1302), and the small peak indexed as (SF) resulted from the stacking faults [28]. Besides these peaks, no other impurities are found in the XRD pattern.

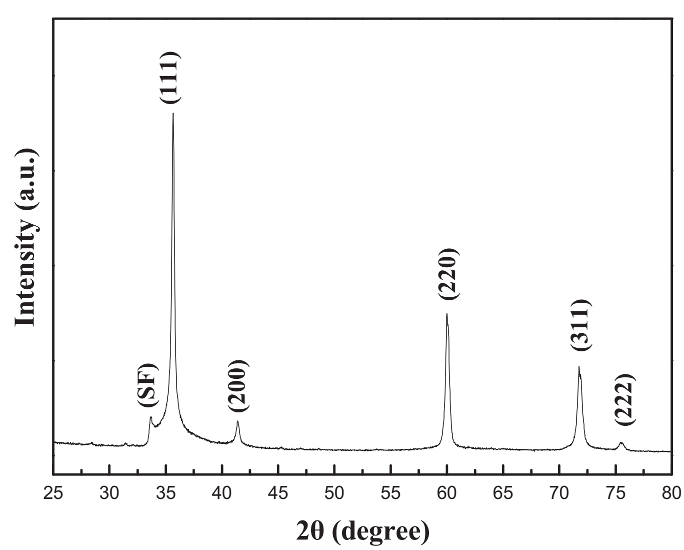

Fig. 2. XRD pattern of SiC nanowires.