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Thermophysical properties of SrY_2O_4

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Abstract

In order to study the applicability of SrY_2O_4 to thermal barrier coating (TBC) materials, we prepared the polycrystalline sample of SrY_2O_4 and measured the thermophysical properties. The melting temperature (T_m) of SrY_2O_4 is 2413 K. The longitudinal and shear sound velocities were measured by an ultrasonic pulse-echo method at room temperature in air, which enabled us to evaluate the elastic moduli and Debye temperature. The heat capacity (C_P) was measured by using a differential scanning calorimeter (DSC) in high purity argon atmosphere. The relationships between the thermophysical properties of SrY_2O_4 were studied.

Keywords: SrY_2O_4; Thermal expansion coefficient; Melting temperature; Young's modulus; Debye temperature; Heat capacity; Thermal barrier coating

1. Introduction

Thermal barrier coatings (TBCs) of partly Y_2O_3 stabilized ZrO_2 (PYSZ) films are widely used to protect hot section parts of aircraft and land-based turbines by reducing the temperature of metal substrates. Their continued development is essential for improving the efficiency and performance of gas turbines by allowing the inlet gas temperature to be increased further. However, this standard material has a limited temperature capability due to accelerated sintering and phase transformations at high temperatures. As a result, a worldwide effort has been undertaken to identify new candidates for a TBC application [1,2].

In general, TBC materials have to fulfill most of the following requirements: the phase must be stable, a low thermal conductivity (<2 $W\,m^{-1}\,K^{-1}$) at high temperatures, a high thermal expansion coefficient (>9 $\times 10^{-6}\,K^{-1}$), high chemical resistance, low sintering rate and high fracture toughness. In our group, we have prepared some alkaline earth perovskites such as $SrCeO_3$ and $SrHfO_3$ and studied their applicability as TBC materials [3–7].

Against this background, we focus on SrY_2O_4 as the new TBC material. SrY_2O_4 is a typical inter oxide in the Y_2O_3–SrO pseudo binary system [8] and the crystal structure is orthorhombic with the space group of Pnam [9–11]. In our previous study [12], the thermal expansion coefficient and thermal conductivity of SrY_2O_4 have been evaluated and it is found that SrY_2O_4 has a potential to be utilized as TBC materials because of the large enough thermal expansion coefficient.

In the present study, a polycrystalline sintered high-density sample of SrY_2O_4 was prepared and the thermophysical properties such as Young's modulus and the heat capacity were measured.

2. Experimental procedure

The polycrystalline sample of SrY_2O_4 was prepared by mixing the appropriate amounts of Y_2O_3 (Furuuchi Chemical, 99.9%) and $SrCO_3$ (Aldrich Chemical, >99.9%), followed by reacting at 1273 K in air. After that, the SrY_2O_4 powder was placed into a 20 mm diameter graphite dye and given a spark plasma sintering (SPS; SUMITOMO COAL MINING Dr Sinter SPS-1020 apparatus) at 1773 K for 3 min under nitrogen atmosphere. The powder X-ray diffraction

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(RIGAKU RINT2000) was performed at room temperature using Cu Kα radiation. In order to determine the chemical composition, the SEM–EDX analysis was performed using HITACHI S-2600H SEM instrument equipped with the energy-dispersive HORIBA EX-200 system. The oxygen analysis was performed using HORIBA EMGA-550 to identify the oxygen concentration of the sample. For measurements of the thermophysical properties, appropriate shapes of the samples were cut from the sintered pellets. The bulk density of the sample was determined by the geometric measurement.

The melting temperature was measured by the thermal arrest method under a reducing atmosphere. The longitudinal and shear sound velocities were measured by the ultrasonic pulse-echo method (NIHON MATECH Echometer 1062) at room temperature in air. The sintered sample was bonded to a 5 MHz longitudinal or shear sound wave echogenic transducer. From the sound velocities, the elastic moduli and Debye temperature were evaluated. The hardness was measured by loading a diamond pyramid-type (with apex 136°) indenter onto the surface of the specimen at room temperature, using a micro-Vickers hardness tester (MATSUZAWA SEIKI MHT-1). The specific heat capacity was measured with a differential scanning calorimeter (DSC; ULVAC) apparatus in the temperature range from room temperature to about 1000 K. The apparatus has a "triple-cell" system and an adiabatic temperature control system which was originally developed by Takahashi and Asou [13]. The principle of the apparatus is briefly summarized in the literature. The measurement was made out in high purity argon (99.999%) atmosphere with a flow rate of 100 ml min^{-1}. The accuracy of the apparatus was checked using an alpha-Al_2O_3 standard.

3. Results and discussion

From the powder X-ray diffraction pattern at room temperature of the sample, it is found that the single phase SrY_2O_4 with the space group of Pnam [9–11] is obtained in the present study. The lattice parameters evaluated from the X-ray diffraction pattern are $a = 1.0090$ nm, $b = 1.1901$ nm and $c = 0.3412$ nm. The bulk density of the sample is 99% of the X-ray density. The chemical composition does not deviate from the stoichiometric composition. The melting temperature determined by the thermal arrest method is 2413 K, which is slightly lower than that in the literature [8]. The sintered sample of SrY_2O_4 shows white color. The sample characteristics are summarized in Table 1.

The relationship between the linear thermal expansion coefficient and melting temperature for SrY_2O_4 is shown in Fig. 1. In this figure, the data of other substances are plotted for comparison [3–7,14]. The average linear thermal expansion coefficient is 10.9×10^{-6} K^{-1} in the temperature range from 300 to 1273 K, which is determined by the high temperature X-ray diffraction method [12]. It is confirmed that the linear thermal expansion coefficient, α_L, varies inversely as the melting temperature, T_m, for many substances, and for some substances the following relationships between α_L and T_m in K have been reported [14]:

$$\alpha_L T_m = 0.019 \text{ (for metals)}, \quad (1)$$

$$\alpha_L T_m = 0.030 \text{ (for fluorite type oxides)}. \quad (2)$$

For barium and strontium series perovskite type oxides, we have confirmed that the products of α_L and T_m show approximately the same value (=0.022). For SrY_2O_4, the product of α_L and T_m equals 0.026, which is slightly higher than those of the alkaline earth perovskites.

Table 1
Sample characteristics and thermophysical properties of SrY_2O_4

Crystal system	Orthorhombic
Space group	Pnam
Lattice parameters at room temperature	
a (nm)	1.0090
b (nm)	1.1901
c (nm)	0.3412
Sample bulk density	
ρ (g cm^{-3})	5.28
ρ (%T.D.)	99
Average linear thermal expansion coefficient (300–1273 K) [8], α_L (K^{-1})	10.9×10^{-6}
Melting temperature, T_m (K)	2413
Young's modulus, E (GPa)	162
Shear modulus, G (GPa)	64
Compressibility, β (GPa^{-1})	8.61×10^{-3}
Debye temperature, θ_D (K)	471
Vickers hardness, H_V (GPa)	9.2
Heat capacity ($C_P = a + bT + cT^2 + dT^{-2}$, 300–1200 K), C_P (J K^{-1} mol^{-1})	$a = 186.6$; $b = -0.0312$; $c = 3.00 \times 10^{-5}$; $d = -2.51 \times 10^6$
Thermal conductivity at 300 K, λ_{300} (W m^{-1} K^{-1})	7.6
Thermal conductivity at 1200 K, λ_{1200} (W m^{-1} K^{-1})	3.4

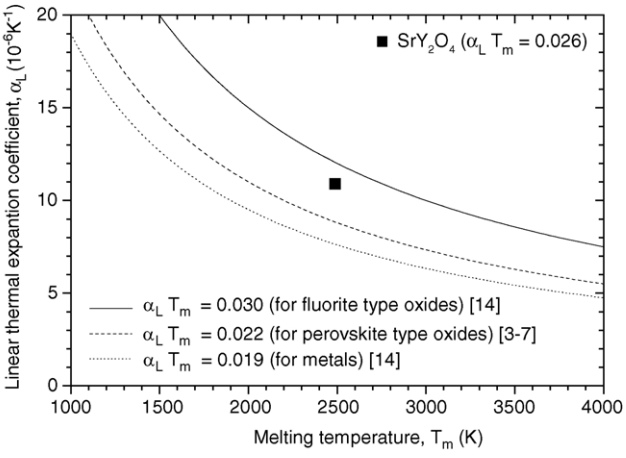

Fig. 1. Relationship between the linear thermal expansion coefficient, α_L, and melting temperature, T_m, for SrY_2O_4, together with the data of other substances [3–7,14].