Archives of Materials Science and Engineering

Volume 114
Issue 2
April 2022
Pages 49-57

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

DOI: 10.5604/01.3001.0016.0025

The microstructure and thermal properties of Yb_2SiO_5 coating deposited using APS and PS-PVD methods

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ABSTRACT

Purpose: The new ceramic material for Enviromental Barrier Coatings (EBC) on ceramic material was developed.

Design/methodology/approach: The ytterbium monosilicate was deposited using two methods: atmospheric plasma spray (APS) and plasma spray physical vapour deposition (PS-PVD).

Findings: Obtained coating was characterized by dense structure and columns typically formed in PS-PVD process were not observed. In comparison with APS-deposited coating, in this method, both elements segregation and formation of ytterbium oxide occurred.

Research limitations/implications: The further research for production of columnar coatings will be necessary.

Practical implications: Developed coatings migh be used for next generations of ceramic materials used for gas turbine and jet engine blades and vanes as a high temperature and corrosion protection.

Originality/value: The first time the ytterbium monosilicate was produced bot by APS and LPPS methods.

Keywords: Ytterbium monosilicate, APS, PS-PVD, EBC, Yb_2SiO_5

Reference to this paper should be given in the following way:

P. Rokicki, M. Góral, T. Kubaszek, K. Dychton, M. Drajewicz, M. Wierzbińska, K. Ochal, The microstructure and thermal properties of Yb_2SiO_5 coating deposited using APS and PS-PVD methods, Archives of Materials Science and Engineering 114/2 (2022) 49-57.

DOI: https://doi.org/10.5604/01.3001.0016.0025

MATERIALS

1. Introduction

Actually, the maximum operating temperature of modern jet engines is limited by melting temperature of nickel superalloys used for turbine blades manufacturing [1]. The different types of coatings are used for protection of turbine blades against high temperature [2]. Recently the ceramic matric composites (CMC) such as SiC are the most promising materials for jet engine construction [3]. Unfortunately the SiC still requires the using of protective coatings called Environmental Barrier Coatings (EBC) for example mulite, YSZ and BSAS (BaO-SrO-Al_2O_3-SiO_2) [4]. The last generation of EBC are based on yttrium and ytterbium silicates [5,6]. Typically the ytterbium silicides EBCs is produced using APS method whith formation of silicon bond-coat [7]. The production of ytterbium monosilicate nanopowders for EBC application is typically conducted by calcination process of silicon and ytterbium oxides [8]. Leite et al. [9] used the ytterbium oxide and oligosilazane. Chen et al proposed the production of three-layer EBC: ytterbium-disilicate/mullite/silicon-carbide [10] and $La_2Zr_2O_7$/$Yb_2Si_2O_7$/SiC [11] using chemical vapour deposition process (CVD). Similar structure of EBC coating was obtained using atmospheric plasma spray (APS) method by Richards et al. [12]. The electrophoretic process might be also used for $Yb_2Si_2O_7$ formation [13].The formation of ytterbium-silicates coating in plasma spraying process was analysed by Garcia et al. [14]. The influence of deposition temperature ytterbium dissilicate by APS method was analysed by Huang et al. [15]. The in-flight particle analysis in APS plasma spraying of ytterbium disilicate and its influence of coating properties was investigated in Oerlikon-Metco company [16]. The addition of 12 wt.% of Yb_2SiO_5 to mulite layer enables to form attractive materials for EBC application [17]. In this type of composite coating with additional Ti_2AlC particles the self-healing mechanism was occurred [18]. The similar phenomena was also observed in SiC-doped ytterbium silicate [19]. The formation of ytterbium silicates during Vacuum Plasma Spraying from Si and ytterbium oxide was observed [20]. The silca activity in high temperature and formation of silicides was investigated by Costa and Jacobson [21]. Chen proposed the using of three-layer EBC containing

During isothermal heat treatment of ytterbium monosilicate the formation of $Yb_2Si_2O_7$ was observed at 1400°C [22]. The mechanism of fracture of ytterbium monosilicate EBC was investigated by Richards et al [23]. Zhang et al [24] investigated the hot corrosion properties of ytterbium monosilicate into molten salt. The Calcium–magnesium–alumino-silicate (CMAS) corrosion of ytterbium silicates was investigated by Wiesner et al [25]. This corrosion mechanism of composite Yb_2SiO_5-8YSZ coating at 1400°C was also analysed by Niedai et al. [26]. The influence of ytterbium disilicate porosity on CMAS corrosion mechanism was investigated by Tejero-Martin et al. [27]. The high-temperature corrosion of $Yb_2Si_2O_7$ in Calcium-Ferrum-Alumina-Silicate (CFAS) condition was also investigated [28]. Summers et al [29] explained the crack propagation and spallation mechanism of ytterbium silicates EBCs. The mechanical properties of ytterbium monosilicate was measured by Kassem et al [30]. The corrosion of ytterbium monosilicate [31] and disilicate [32] in water vapour was also investigated. The influence of high-velocity water vapours on sdisilicide EBCs was described by Ridley and Opila [33]. The corrosion of SiC CMC with ytteribium monosilicate EBC in high temperature water steam was also analysed by Nasiri et al. [34]. The solid-particle erosion of $Yb_2Si_2O_7$ was tested by NASA [35].

Analysis of actual state-of-art publications in ytteribum silicates suggest that plasma spraying (APS, LPPS, PS-PVD) is the main method this type of coating production. The corrosion properties in isothermal and cyclic oxidation condition as well as in steam, CMAS and CFAS was deeply investigated. There is no many references in the case of thermal properties of ytterbium monosilicate at high temperatures. In present article the microstructure and thermal properties of Yb_2SiO_5 formed using conventional atmospheric plasma spraying (APS) as well as novel plasma spray physical vapour deposition (PS-PVD) were investigated.

2. Experimental

In the all test the Yb_2SiO_5 powder produced by Treibacher [10] was used for both experimental plasma-spraying processes. The SiC flat sample 5 mm thick was used as a base material for coating production. The Yb_2SiO_5 coatings were produced using APS and PS-PVD methods.

The atmospheric plasma spraying process (APS) was conducted using A60 plasma system (Thermico, Germany). The high-energy plasma energy process parameters typically used for YSZ coatings production [36] were selected: power current 700 A, Ar flow 50 NLPM (normal litres per minute), H_2 flow 6 NLPM, powder feed rate 10 g/min, robot movement speed 150 mm/s. Additionally the preheating process by moving of plasma torch without powder feeding was used before coating formation.

The second coating was produced by PS-PVD method using industrial LPPS-Hybrid system (Oerlikon-Metco) in Research and Development Laboratory for Aerospace Materials (Fig. 1). As initial parameters the typically used for PS-PVD process were selected [37] power current 2200 A, powder feed rate 2 g/min, plasma gas flow: Ar: 35 NLPM, He 60 NLPM, chamber pressure 150 Pa. Unfortunately the coating was not formed using this parameters so the power current was decreased to 1800 A and powder feed rate was increased up to 20 g/min. When new process parameters were used there was not observed problems with coating formation.

Fig. 1. The overview of industrial PS-PVD system used in experimental

The μXCT computer tomography of PS-PVD deposited coating was conducted using VERSA 520 device.

Analysis of thermal diffusivity was performed using a Netzsch LFA 427 in the temperature range from 700 to 1100°C and a flow of argon of 50 mL/min. Before the measurement of thermal diffusivity, the samples were covered with a graphite layer. The thermal diffusivity was measured for base material – ceramic layer system and it was only a comparative measurement.

3. Results

3.1. The ytterbium silicate coating produced by APS method

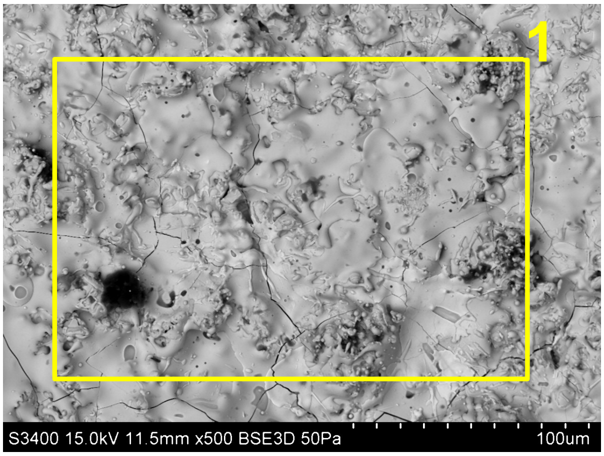
The surface of deposited ceramic coating was characterized by morphology similar to typical APS-sprayed YSZ TBCs [38] (Fig. 2a,b).

It was characterized by presence of unmelted powder particles and cracks (Fig. 2b). The chemical composition analysis on surface showed only the presence of oxygen and ytterbium. The silicon was not detected on the surface (Fig. 2a, Tab. 1, area 1).

Table 1.
Results of chemical composition analysis in areas marked in Fig. 2a, and Fig. 3a,b

Area	Element concentration, at.%		
	O	Si	Yb
1	65.3	-	34.7
2	66.8	5.7	27.5
3	66.6	-	33.4
4	65.1	-	34.9
5	41.9	30.4	27.7

a)



b)

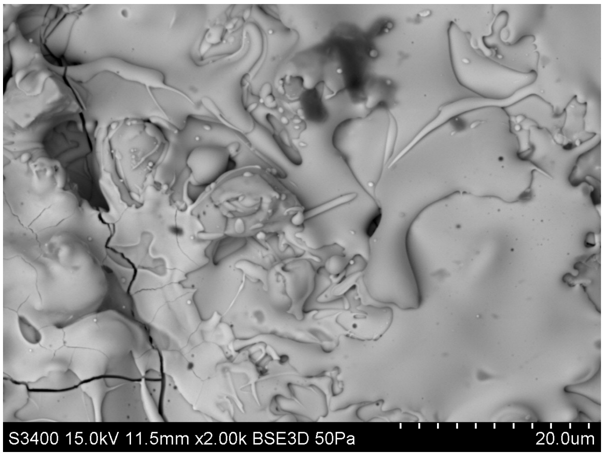


Fig. 2. The surface morphology (a,b) of ytterbium monosilicate coating produced by APS method on SiC with marked area (a) of chemical composition analysis

The structure of coating had a typical morphology of ceramic coating produced by conventional plasma spraying process (Fig. 3a). Some cracks were observed in coating similarry to reported by Garcia et al [39]. The results of chemical composition from whole cross-section (area 2 in Fig. 3a, Tab. 1) showed presence of main components of coating: ytterbium, silicon and oxygen. Two characteristic areas in the obtained coating were observed. The brighter areas (marked as 3 and 4 in Fig. 3b, Tab. 1) did not contained silicon. According to ref. [14] it migh be connected with presence only of ytterbium oxide formed from decomposited ytterbium monosilicated in darker area (marked as 5 in Fig. 3b, Tab. 1) the high concentration of silicon as well as ytterbium and oxygen were detected. According to Garcia et al. [39] the Yb_2SiO_5 was observed in this area.

a)

b)

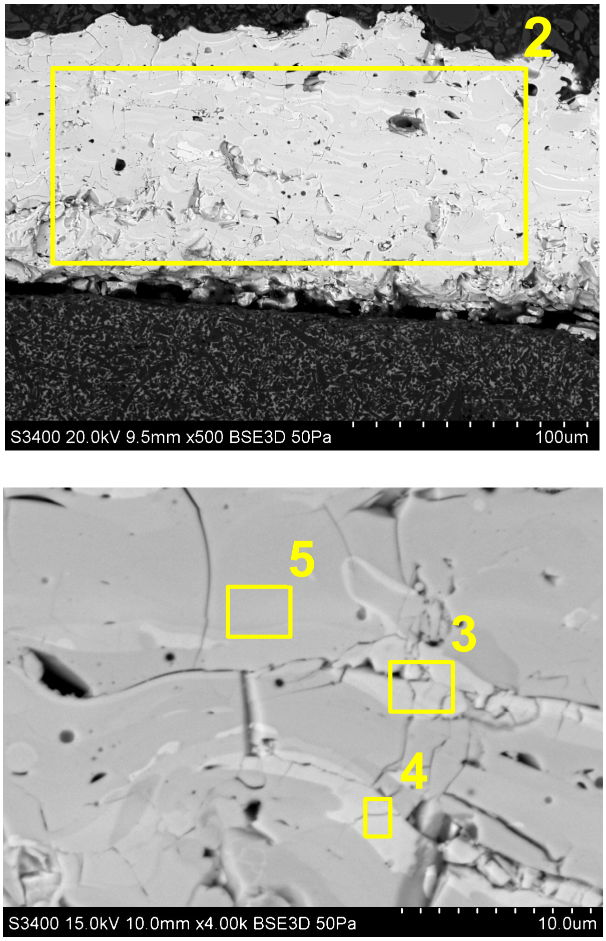


Fig. 3. The microstructure (a, b) of ytterbium monosilicate coating produced by APS method on SiC with marked areas of chemical composition analysis

3.2. The ytterbium silicate coating produced by PS-PVD method

For comparison the ytterbium monosilicate coating about 200 μm thick was also produced using PS-PVD process. Surface morphology (Fig. 4a,b) of deposited coating was comparable to dense structure of YSZ coating obtained by PS-PVD method [37] and formed in APS method. The re-melted particles of a small size were observed on the surface of coating (Fig. 4b). The results of chemical composition analysis from the surface area (marked as "1") show presence of silicon, ytterbium and oxygen (Fig. 4a, Tab. 2).

The microstructure of cross-section of coating was analysed using computer tomography method (Fig. 5a). The thickness of coating deposited on samples was uniform. There were no changes in the coating morphology in the areas of sharp edges of the sample (Fig. 5b)

a)

b)

c)

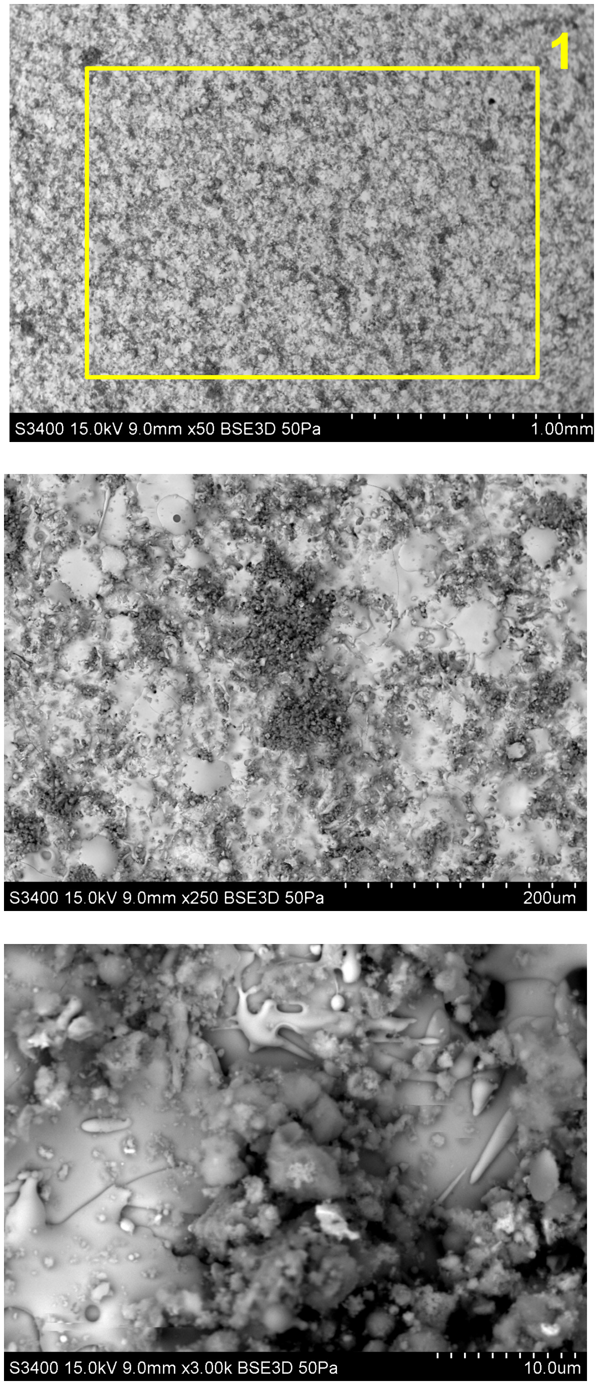


Fig. 4. The surface morphology (a,b,c) of ytterbium monosilicate coating deposited by PS-PVD method on SiC substrate with marked area of chemical composition analysis

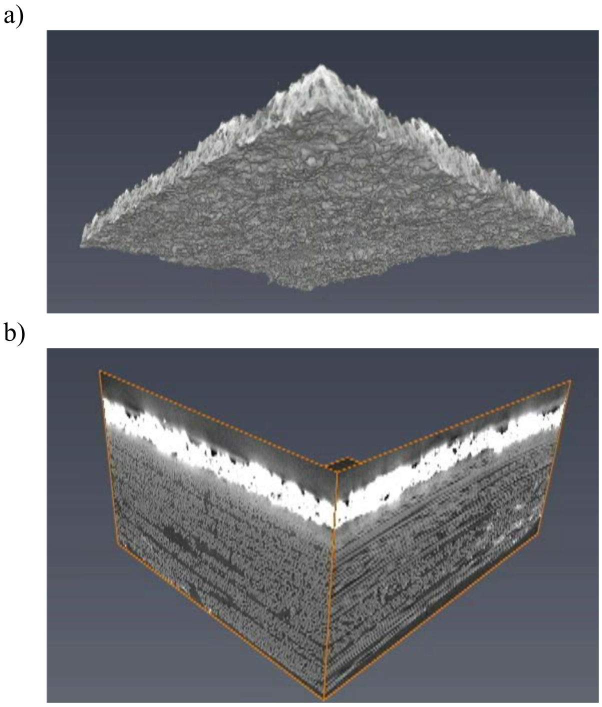


Fig. 5. The tomography structure of cross-section of ytterbium monosilicate coating formed using PS-PVD method

Table 2.
Results of chemical composition analysis on the surface and on cross section of ytterbium monosilicate coating obtained by PS-PVD method on SiC substrate with marked areas on Figs. 4a and 6c

Area	Element concentration, at.%		
	O	Si	Yb
1	61.5	7.6	30.8
2	64.1	20.3	15.6
3	60.0	30.1	9.9
4	60.0	-	40.0

Microstructure of obtained Yb_2SiO_5 coating is dense and of columnar structure, usually observed in YSZ coatings formed in PS-PVD process [37] (Fig. 6a). What is important, the similar structure was formed by Zhang et al. using higher power current [40]. The Yb, Si as well as O were detected in visible darker areas of the coating (area 2, 3, Fig. 6c, Tab. 2). According to ref. [14] and [41] the pure ytterbium monosilicate was formed in this area. In the area 4 marked in the Figure 3b ytterbium was not detected. The above results are similar to the coating obtained by conventional APS process. Thus, the observation results confirm decomposition of ytterbium monosilicate during PS-PVD process [41], in accordance with equation:

$$Yb_2SiO_5(s) \rightarrow Yb_2O_3(s) + SiO_2(g) \quad (1)$$

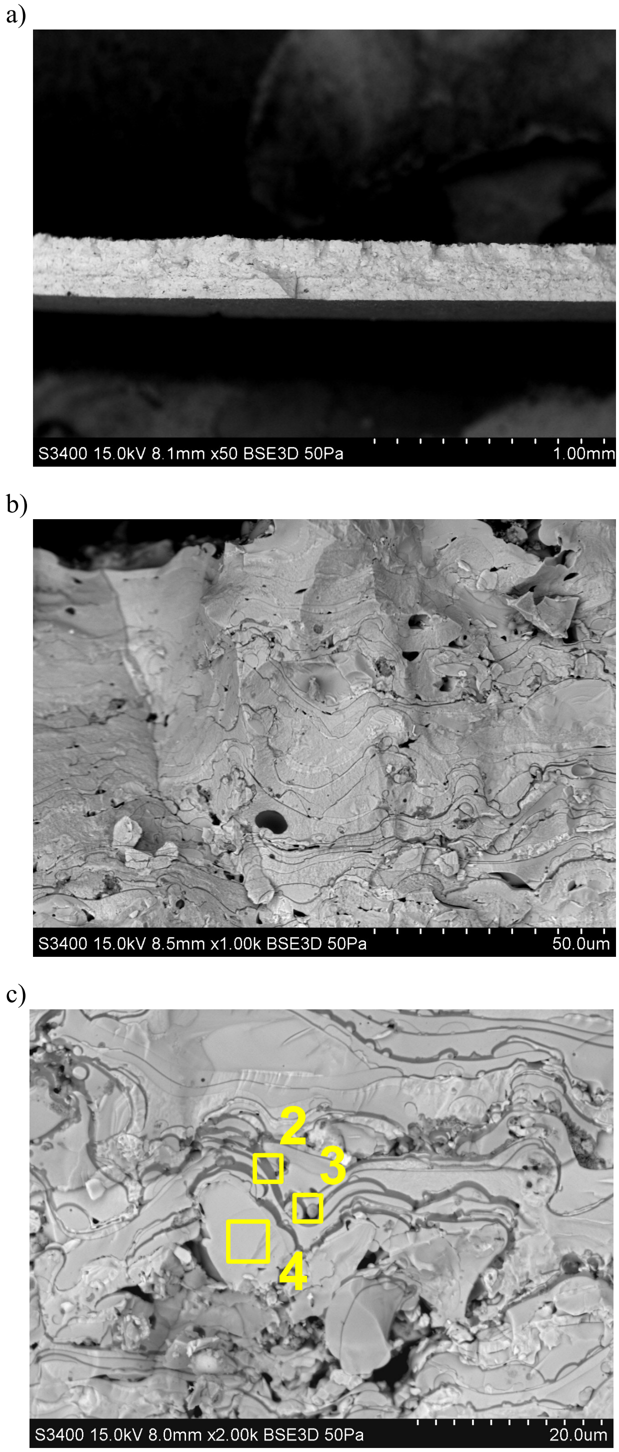


Fig. 6. The microstructure (a-c) of ytterbium monosilicate coating deposited by PS-PVD method on SiC substrate with marked areas of chemical composition analysis

3.3. Thermal diffusivity of deposited coatings

There is no specific heat values measured for ytterbium monosilicate. In this case the comparative analysis of thermal diffusivity of coating produced using both methods was conducted (Fig. 7). The value of thermal diffusivity for PS-PVD coating was significantly higher than measuref for APS-sprayed ytterbium monoslilicate coating. It was probably connected with more dense structure of coating deposited in lower pressure and higher velocity of plasma plume.

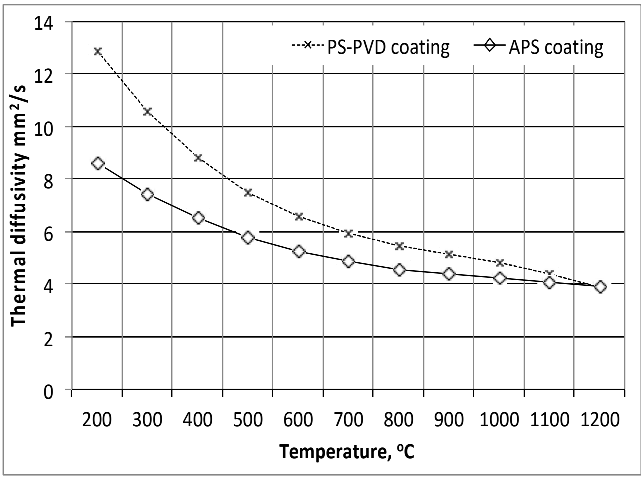


Fig. 7. The thermal diffusivity of SiC with ytterbium monosilicate coating deposited by APS and PS-PVD methods

4. Conclusions

The two methods for Yb_2SiO_5 coatings production were used. The obtained results showed that using both APS and PS-PVD process enables to form dense thick layer of ytterbium monosilicate. In the case of coating produced by APS method the lamellar structure was achieved similar to typical YSZ (Yttria stabilized zirconia). Some cracks and unmelted particles on the surface were observed. The results of chemical composition analysis showed segregation of elements as results of phase transformation in APS-sprayed coating similar to results obtained by Garcia [39]. The unmelted particles as well cracks in the coating was observed. The segregation of elements in APS-deposited Yb_2SiO_5 coating was also detected. The PS-PVD was used as second method for ytterbium monosilicate deposition. The obtained coating was characterized by dense structure and columns typically formed in PS-PVD process were not observed [14-16]. Similar to APS-deposited coating segregation of elements and decomposition of ytterbium monsilicate in PS-PVD process was confirmed. The deeper analysis of phase transformation and chemical reactions in ytterbium monosilicate have to be deeply investigated in further research. The initial measurement of thermal properties showed that APS-sprayed ytterbium monosilicate was characterized by lower thermal diffusivity that deposited using PS-PVD method. It was connected with probably higher porosity of coatings produced using APS method in comparison with dense coating formed using PS-PVD method. It suggests that deeper investigation of Yb_2SiO_5 thermal properties is necessary.

Acknowledgements

The author thanks Dr Willy Kuntz and prof. E. Zschech (IKTS, Dresden) for preparation of CT structures of obtained coatings.

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