Chapter 4
Advances in Low Thermal Conductivity Materials for Thermal Barrier Coatings

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ABSTRACT

One of the areas of research that continue to attract researchers worldwide is the development of thermal barrier coatings (TBCs) especially associated with the design of new ceramic topcoats with low thermal conductivity and a high coefficient of thermal expansion. The purpose of this chapter is to present the advances that have been achieved regarding ceramic topcoats in the last decades, making a historical journey that culminates with the contributions of this decade. The introduction of new crystalline structures and chemical compositions have opened the door to the real possibilities of replacing yttria-stabilized zirconia (YSZ) to ensure the optimal thermomechanical-chemical properties required by TBCs. Future research directions associated with this topic are also provided.

INTRODUCTION

Thermal barrier coatings (TBCs) can be defined as advanced deposited material systems, operating at high temperatures to offer improved thermal stability and lower thermal conductivity These are placed on metal surfaces to protect the components of the hot section of gas turbine engines, and thereby, achieving higher fuel efficiency and lower emission objectives (Backman, 1992; Padture, 2002; Herzog, 2006). These coatings additionally improve erosion and impact resistance, which are crucial to increase engine durability and performance. Unfortunately, these coatings are susceptible to accelerated degradation due to deposition of silicates (known as CMAS) by environmental debris such as dust, sand, and ash that

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adheres to them (Vaßen, 2012; Poerschke, 2017). The advanced materials used for this purpose are based on combinations of doped transition metal oxides with rare earth oxides, which reduce oxidation and thermal fatigue in the metal part. The most commonly used oxides are yttria stabilized zirconia (ZrO_2-Y_2O_3), mullite ($3Al_2O_3$-$2SiO_2$), alumina (Al_2O_3), ceria (CeO_2), lanthanum zirconate ($La_2Zr_2O_7$), lanthanum oxide (La_2O_3), oxide niobium (Nb_2O_5), and praseodymium oxide (Pr_2O_3) (Vasen, 2000; Cao, 2004; Tarasi, 2011). New and innovative materials for TBCs are being introduced such as $LaTi_2Al_9O_{19}$ (LTA) (Xie, 2011), lanthanide tantalate ($RETa_3O_9$) (where RE = Ce (Cerium), Nd (Neodymium), Sm (Samarium), Eu (Europium), Gd (Gadolinium), Dy (Dysprosium), Er (Erbium)) (Chen L, 2018), dysprosium-tantalum oxide (DTO) (Wu, 2018), magnesium-silicon oxide (MSO) (Chen S, 2019), lanthanide niobate (Ln_3NbO_7) (LNO) (where Ln or L = Dy (Dysprosium), Er (Erbium), Y (Yttrium), Yb (Ytterbium)) (Yang, 2019), zirconium lanthanate ($Zr_3Ln_4O_{12}$) (where Ln = La (Lanthanum), Gd (Gadolinium), Y (Yttrium), Er (Erbium), and Yb (Ytterbium)) (Zhao M, 2019), magnetoplumbite ($LnMgAl_{11}O_{19}$) (where Ln = La (Lanthanum), Pr (Praseodymium), Nd (Neodymium), Sm (Samarium), Eu (Europium), Gd (Gadolinium)) (Zhao Y, 2019), and gadolinium-zirconium oxide (GZO) (Vaßen, 2020).

Materials for thermal barriers must meet five main requirements: 1) low thermal conductivity, 2) high thermal expansion coefficient (CTE), 3) high melting point, 4) excellent damage tolerance, and 5) moderate mechanical properties (Liu, B. 2019). Metal surfaces, where thermal barrier coatings are deposited, are based on high temperature superalloys. These are exposed to dangerous environments and hot combustion of engines and turbines used for propulsion and power generation (Zhao M, 2019).

In addition, thermal barrier coatings guarantee the phase stability of the materials to be coated, offer corrosion resistance and high fracture toughness. These coatings continue to be used on the hot parts of gas turbines with two purposes: 1) to increase turbine efficiency and 2) to extend the life of these metal parts (Zhou, 2014). A high coefficient of thermal expansion increases the service life of a thermal barrier coating (TBC) (Zhou, 2020). The global market for the manufacture of thermal barrier coatings, considering both materials and equipment, in 2015 was estimated in the order of 7.58 billion US dollars. Its compound annual growth rate is 7.79% and it is expected to reach 11.89 billion US dollars by 2021 (Vardelle, 2016).

Until now, vapor deposition techniques are the main techniques for the manufacture of thermal barrier coatings (Vaßen, 2010). The main techniques are based on electron beam physical vapor deposition (EB-PVD) and atmospheric plasma spray (APS). The first technique produces columnar microstructures and is used for thermomechanically loaded blades of gas turbines, and the second offers better robust operation and economic viability compared to the first.

In this chapter, a brief history describing the evolution that thermal barrier coatings have experienced is presented. Current directions in thermal barrier coatings research and recent worldwide progress are also analyzed. This study will provide reference to develop new lower thermal conductivity materials used as thermal barrier coatings. Also, potential challenges and opportunities are briefly highlighted in order to minimize the thermal conductivity of the materials used in the coatings in the coming decades.

This chapter has been divided as follows: In the section titled *Background*, a description of the basic concepts, materials and common problems found in thermal barrier coatings is presented. Furthermore, a brief history of the evolution of coatings is provided in this section. Subsequently, in the section entitled *Why use low thermal conductivity?*, a brief discussion on the importance of further decreasing the conductivity of the material used as a thermal barrier coating is presented with a view to introducing new materials. Subsequently, in the section titled *Solutions and Recommendations*, some alternative coating materials that have a lower thermal conductivity than those presented in the *Background* section are