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High-temperature electromagnetic interference shielding of layered Ti_3AlC_2 ceramics

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ABSTRACT

The electromagnetic interference (EMI) shielding of dense Ti_3AlC_2 ceramics with distinct microstructures were investigated up to 800 °C. Ti_3AlC_2 exhibits high EMI shielding effectiveness (SE) around 30 dB which was mainly attributed to high electrical conductivity and complex permittivity. Besides, the EMI shielding were sensitive to the microstructure. Ti_3AlC_2 with high aspect ratio grains and certain degree of texture were preferred for high SE indicating that the typical layered structure also contributes to the high shielding capability. These results indicate that layered Ti_3AlC_2 ceramics could be considered as promising structural EMI shielding materials at high temperatures.

Metal-, carbon- and conducting polymer-based composites have been commonly developed for the shielding of electromagnetic interference (EMI) during the past decades [1–5]. With the ever fast growing applications of EMI shielding components in areas of aircraft, aerospace and automobiles, being lightweight, mechanically tough and thermophysically stable at high temperatures become important factors for practical EMI shielding applications in addition to high EMI shielding performance [6]. Metal-based composites generally suffer from several disadvantages including heavy weight, poor corrosion resistance and inferior mechanical properties especially at high temperatures. Although carbon-based composites exhibit excellent EMI shielding properties, they could not act as structural shielding materials owning to their low mechanical strength. Electrically conductive polymer-based composites containing nanofillers such as metal particles, carbon nanotubes (CNTs) [7,8], carbon nanofibers (CNFs) [9] and graphene nanoplatelet (GNP) [7,8,10] have gained growing popularity because of their light weight, flexibility and resistance to corrosion. Nevertheless, their low mechanical strength and poor temperature stability make them almost impossible to be used in harsh environments. Consequently, for applications which require high strengths, good temperature stability as well as EMI shielding capabilities, novel EMI shielding composites need to be explored [6].

Recently, advanced ceramic composites have received considerable attentions as fascinating candidates of high-temperature EMI shielding materials due to their relatively low density, excellent mechanical properties, satisfactory corrosion and oxidation resistance, high permittivity and potential structural applications at high temperatures [11–14]. Nevertheless, the generally inferior electrical conductivity becomes a major obstacle to obtain high EMI SE in ceramics. Although the electrical conductivity and EMI SE of ceramics could be significantly enhanced by incorporating highly conducting CNTs or CNFs [11–13], the application of CNTs or CNFs in ceramic composites is hindered by the difficulty of homogenous dispersion due to their tendency to aggregate and the poor oxidation resistance of CNTs and CNFs at high temperatures. Therefore, intrinsically electrical conductive ceramics become greatly desired as promising high temperature EMI shielding materials.

A class of layered ternary transition-metal carbides and nitrides with a general formula of $M_{n+1}AX_n$ (shortly refereed as MAX phase, wherein M is an early transition metal, A is an A-group element, X is either C or N, and n varies from 1 to 3) have attracted tremendous attentions since their discovery due to their unique combination of both ceramic- and metal-like properties [15–17]. Like most ceramics, the MAX phases are elastically stiff and resistant to chemical corrosion; similar to metals, the MAX phases exhibit good machinability, high thermal and electrical conductivity. Moreover, some MAX phases show excellent oxidation resistance at high temperatures [18]. Therefore, MAX phases are promising lightweight EMI shielding candidates for high-temperature and structural applications. Ti_3AlC_2 and Ti_3SiC_2 are two typical MAX phases and therefore have been extensively studied. Further, Ti_3SiC_2 has been demonstrated to show extremely high EMI SE at room temperature [19]. While compared to Ti_3SiC_2, Ti_3AlC_2 exhibits much better oxidation resistance at high temperatures and is therefore more suitable for high-temperature applications [18]. Nevertheless, the high-temperature EMI shielding performances of MAX phase ceramics still have not been

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explored so far to our best knowledge. Moreover, the layered structure of MAX phase was thought to be favorable for EMI shielding and exceptionally high EMI SE was recently reported in two-dimensional MXene Ti_3C_2 which was generally obtained by stripping A-element from MAX phases [20]. However, the relationship between EMI SE and microstructures of ceramics still needs to be further clarified. In this study, two type of dense Ti_3AlC_2 ceramics with different microstructures were fabricated by hot-pressing and their EMI shielding properties at X-band frequency (8.2–12.4 GHz) were systematically investigated up to 800 °C in order to explore the possible applications of MAX phases as EMI shielding materials at high temperatures. The influence of ceramic microstructures on EMI shielding properties was systematically studied.

Two types of Ti_3AlC_2 powders were utilized in this study: the first type (≥98%, ~300 mesh) was purchased from Forsman (China) and the second type was synthesized from Ti, Al and C powders at 1560 °C in Argon atmosphere. Two types of Ti_3AlC_2 powders were placed in a 50 mm diameter graphite die directly without any mechanical vibrations and hot-pressing sintered in vacuum at 1400 °C for 30 min. A uniaxial pressure of 30 MPa was applied during sintering. The Ti_3AlC_2 ceramics prepared from the first and second types of Ti_3AlC_2 ceramics were named as type-A and type-B respectively. The bulk density of the sintered samples was measured by the Archimedes method. The microstructures of the specimens were observed using scanning electron microscopy (SEM).

The electrical conductivity was measured by the four-terminal method. For EMI SE characterization, specimens with dimensions of 22.86 mm × 10.16 mm × 1.50 mm were cut and polished. For a comparison, pure Ti metal plate with the same dimension was also prepared.

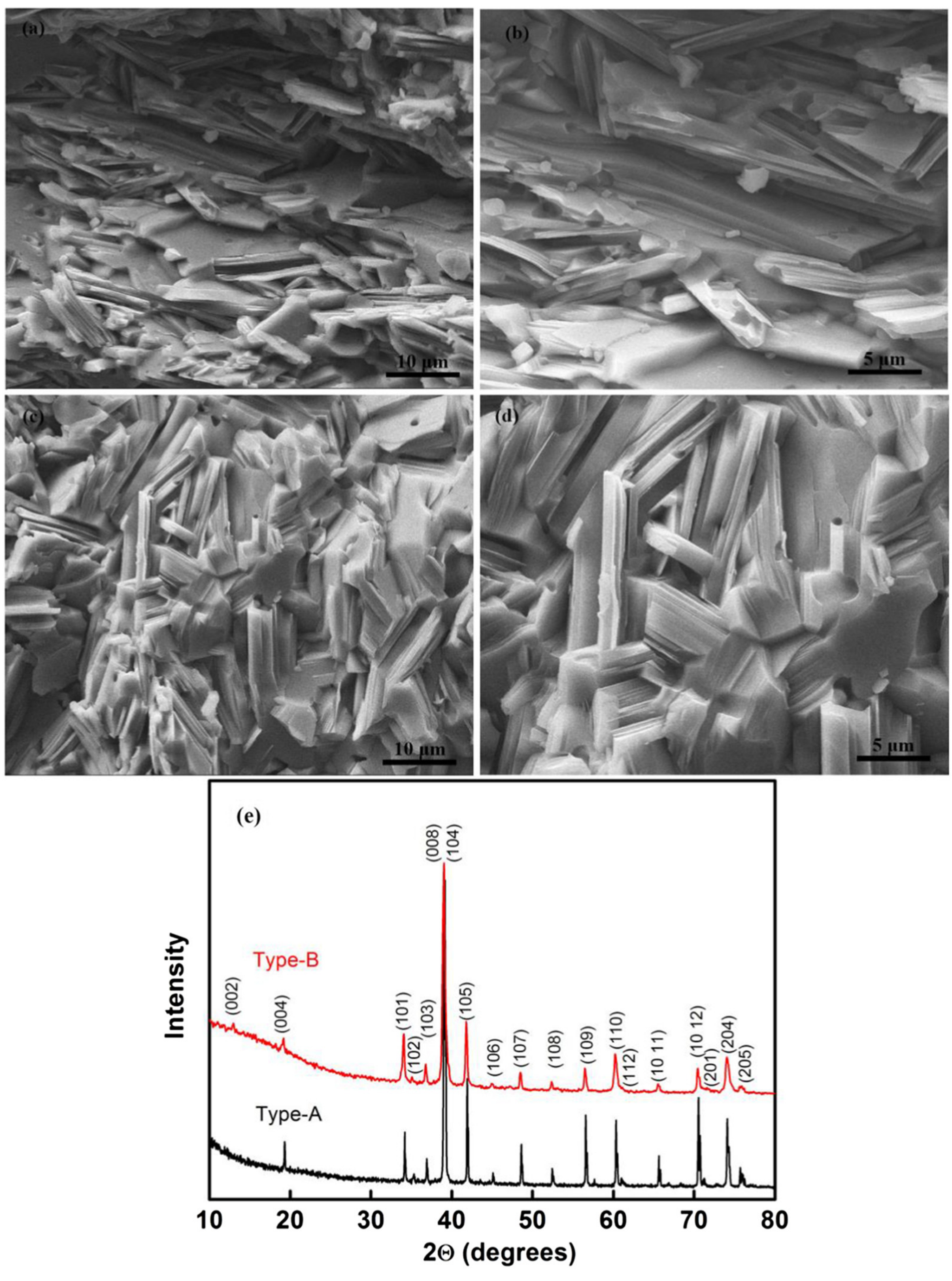

Fig. 1. Fracture surfaces of type-A ((a) and (b)) and type-B ((c) and (d)) Ti_3AlC_2 ceramics; (e) corresponds to the XRD patterns of type-A and type-B Ti_3AlC_2 ceramics.