Ceramics Manufacturing by Spark Plasma Sintering

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Keywords: Spark Plasma Sintering, Ultra high temperature ceramics, Transparent Ceramics, Diamond

Spark plasma sintering (SPS) or electric current assisted sintering (ECAS) is versatile technique to consolidate ceramic materials. In SPS, electrical current directly passes through specimens if conductive, causing a high heating rate commonly 100°C/min, which is beneficial for densification. We have been developing novel ceramic materials by using SPS. The characteristics of SPS are capable to sinter hardly-sinterable ceramics, to sinter perfectly in a short time, and to sinter materials massively for industrial application. Several research outcomes are presented.

SiC, ZrB, TiC, TiB_2 so-called ultra-high-temperature ceramics (UHTCs) are difficult to sinter by conventional sintering technique, while SPS can fabricate these monolithic materials and their composites can be consolidated. We have fabricated UHTCs such as SiC-ZrB_2, TiN-TiB_2, SiC-SiO_2 composites by SPS. SPS can develop high performance high-temperature structural ceramics.

SPS is also advantageous to fabricate transparent ceramics. Transparent ceramics are a kind of perfect ceramics having density more than 99 %, and residual pores should be thoroughly eliminated. Although transparent ceramics can be synthesized by hot-pressing (HP) or hot isostatic pressing (HIP), it takes a long time and high temperature. SPS can make transparent ceramics in a short time, without significant grain growth, resulting in mechanically strong and uniform dopant distribution. We have fabricated various transparent ceramics by SPS. Lu_2O_3 is a candidate host material for laser and scintillator because of wide band gap and no light absorption in the band. We have made Nd^{3+} doped Lu_2O_3, and first exhibited laser emission by SPS transparent ceramics. Transparent Ce^{3+} doped YAG ($Y_3Al_5O_{12}$ Yttrium Aluminium Garnet), a candidate material of white light emission, was also prepared by SPS.

The characteristic of SPS is a short time to sinter. SPS can make diamond-based composite. Without transformation of diamond to graphite, diamond-based composite can be fabricated by SPS. Diamond alone cannot be sintered, whereas diamond with SiO_2 glass can be consolidated. SiO_2 can be densified quickly by plastic flow without crystallization by SPS. SiO_2 glass can enter in-between diamond grains. Amorphous SiO_2 is more ductile than crystalline SiO_2, and thermal expansion of SiO_2 is lower than that of diamond, leading high ductility by compressive stress in SiO_2. The diamond-based composite was consolidated to 94 % of density and 40 GPa of Vickers hardness.

SPS is not only for ceramics. Metals and alloys are much easier to consolidate. Highly conductive and high strength Cu-Zr/Cu composite by SPS showed high erosion resistance, which are commercialized to welding electrodes, shank and chip.