Field Assisted Sintering of Ceramics – Are there m(any) similarities?

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For highly demanding applications in electronics, energy, healthcare and defence sectors the usage of advanced ceramics and their hybridised products with metals and polymers is substantial, critical and irreplaceable. All these products however require densification/sintering, a high temperature process (e.g. 1000 – 2000^{o}C) that in industry can take days. The amount of energy needed, and CO_2 emitted, is therefore very significant; sometimes energy can account for 30% of costs. Further conventional processing technologies generally fall short in delivering multifunctional hybrid materials with the required performance and reliability. The fabrication of these functional devices/components are often plagued by interfacial issues, unwanted grain growth, migration of one component into another and limitations of co-firing dissimilar materials etc. Thus rapid and efficient sintering methods such as Spark Plasma Sintering (SPS), Microwave Assisted Sintering (MAS), and Flash Sintering (FS) are continuously being developed. These approaches are together referred as Field Assisted Sintering Techniques (FAST), and in all these cases application of electric, magnetic and/or electro-magnetic field were demonstrated to have a positive effect on ceramic densification. For example, the flash sintering method, for reasons that are far from fully understood, has yielded full densification in very short periods at very low temperatures, e.g. 5 s at 850^{o}C for zirconia, and at a surprisingly low temperature of 325^{o}C for Co_2MnO_4 spinel ceramics. Thus the associated time and energy advantage is estimated to be staggering, as well as the ability to tailor the required micro/nano structure and in turn the performance.

Many plausible explanations have been proposed such as electric sparks and plasmas at particle-particle contacts, joule heating, additional driving force provided by the E/H fields, and temperature-gradient-driven diffusion for field-enhanced sintering of materials – however a clear understanding of the underlying atomistic mechanisms still remains clouded. In this talk, we will have a closer look at two of the FAST methods, namely Microwave Sintering and Flash Sintering – one a well-established and the other a newly emerging densification method. The MAS method can be suitable for the processing of various simple and complex shaped engineering components, the early use of FS method was restricted to dog-bone shaped ceramic specimens – that are both difficult to make and do not have much industrial applicability. However, the recent developments have demonstrated that FS can be used to sinter different sample shapes. At Loughborough we investigated the feasibility of sintering ZnO-varistors, $BaTiO_3$-capacitors, CCTO dielectrics, Multilayer metal-ceramic hybrids, YSZ and ZTA components using both MS and FS methods along with simultaneous measurements of shrinkage, online thermal distribution mapping and atmospheric control. This talk will review these new developments on FS along with the operative mechanisms in comparison with microwave processing.