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Hot pressing of nanocrystalline zinc oxide compacts: Densification and grain growth during sintering

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Abstract

Sintering behavior of nanocrystalline zinc oxide (ZnO) powder compacts using hot pressing method was investigated. The sintering conditions (temperature and total time) and results (density and grain size) of two-step sintering (TSS), conventional sintering (CS) and hot pressing (HP) methods were compared. The HP technique versus CS was shown to be a superior method to obtain higher final density (99%), lower sintering temperature, shorter total sintering time and rather fine grain size. The maximum density achieved via HP, TSS and CS methods were 99%, 98.3% and 97%, respectively. The final grain size of samples obtained by HP was greater than that of TSS method. However, the ultra-prolonged sintering total time and the lower final density (88 ks and 98.3%) are the drawbacks of TSS in comparison with the faster HP (17 ks and 99%) method.

Keywords: A. Hot press; A. Grain growth; D. ZnO; Densification

1. Introduction

Nanocrystalline materials have received a great deal of attention over the last years. These materials are potentially attractive for many applications since the reduction of the grain size to the nanometer scale can improve their physical and mechanical properties [1–3].

Zinc oxide (ZnO) is one of the most important multi-functional materials, which can be used in many fields, such as optoelectronic devices, gas sensors, solar cells and varistors [4–7]. It was found that the physical properties of ZnO are directly contributed by the grain size. For instance, Duran et al. [1] have also, reported that ZnO with a smaller grain size can exhibit larger breakdown voltages. The grain size reduction is, additionally, exposed to enhance the conduction nonlinearity [8]. Besides, Wang and Gao [2] recently reported the optical and electrical properties of ZnO to be strongly depended on the volume of grain boundaries. Therefore, it is of the great significance to control the grain size of ZnO compacts thorough the sintering procedure. However, manufacturing of dense ZnO samples with a fine microstructure using traditional forming techniques followed by pressureless sintering has not proven easy. Roy et al. [9], For example, sintered ZnO nanopowders (30 nm) at 900 °C for 6 h and reported the relative final density of 99% TD, while the final grain size was around 2 μm.

There have been always three main approaches, usually applied to avoid the accelerated grain growth associated with densification and, therefore, provide fine microstructures. The first one is the addition of second phase particles (dopants) to modify diffusion processes, prevent the grain boundary migration and, hence, suppress the grain growth. Nevertheless, the second phase can be destructive to densification and physical behavior. Han et al. [10] have, for instance, shown that, while the addition of Al significantly inhibits the grain growth of ZnO and increases the grain growth kinetic exponent from 3 to 6 for pure and Al-doped ZnO, respectively, the ZnO system s a notable decline in the densification rate. Sedky et al. [11] have studied the sintering behavior of Fe-doped ZnO samples. They have reported that in spite of the grain growth suppression caused by the Fe content, the abovementioned approach diminishes final density of the sintered specimens. On the other hand, their investigation exposed the detrimental effect of Fe dopants on the electrical conductivity of pure ZnO samples.

The second approach is a new technique called two-step sintering (TSS). This method offers a promising approach for

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