Cold Sintering Process of Hexagonal Boron Nitride Bulk Ceramic

H. Nishiyama, J. Mena-Garcia, H. Shimizu, and C.A. Randall

The advancements in AI, computational, and communication technologies, along with high-power, high-frequency electronics, necessitate advanced packaging materials. These must exhibit high mechanical strength, low dielectric loss, and high thermal conductivity at low cost for future technological applications. Higher operational frequencies require broader communication bandwidth, but current commercial substrate materials are inadequate, causing power dissipation and localized heating that affects adjacent components and reliability. Developing dielectric materials with superior thermal conductivity is essential for viable, lower-cost alternatives in power electronics packaging.

Cold sintering process (CSP) presents an option for the fabrication of aforementioned innovative materials, which viability has been demonstrated for numerous materials systems for a wide extent of applications. This is typically a chemomechanical process analogous to the pressure solution creep sintering mechanism, characterized by the collective interaction of dissolution, mass transport, and precipitation in the solid/solvent system under an applied pressure. The cold sintering process typically occurs at temperatures below 300°C under applied pressures of a few hundred megapascal (MPa), in the presence of a transient liquid phase that controls the dissolution process. One of the primary appeals of the cold sintering process lies in its ability to densify bulk materials which requires a high temperature to sinter. Ceramic substrate materials with high thermal conductivity include such as Al2O3, AlN, Si3N4, but they typically require high temperatures of around 1600-2000°C for sintering. However, even with such materials, the sintering temperature can be significantly reduced by using CSP technique.

In recent years, it has been reported that 2D materials can be densified by cold pressing (CP), which involves uniaxial pressing of dry powder. However, there are several issues with these reports. In the case of CP, the pressure required to achieve a dense body is excessively high. Therefore, we decided to apply a wet-type low-temperature sintering method known as cold sintering using hBN micro flakes. Unlike CP, CSP typically involves dissolution and reprecipitation reactions, which breaks particle surface chemical bonds and reforms them under pressure solution creep mechanisms between particles, and transports along chemical potential gradients. The objective of this work is to provide a method for producing a dense body made with hBN micro flakes using the wet-type CSP. This includes an essential understanding of the size dependence of hBN flakes, the role of transient liquids such as water, and the presence or absence of the heating process in CSP of hBN. Additionally, we report on the feasibility of fabricating multilayered structures with internal electrodes using CSP.