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# Temperature ultra-stable BaTiO3-based ceramics with near-nano grains via the core-shell structure design and controlled grain growth

## 摘要

在各类高精度仪器系统中，要求多层陶瓷电容器（MLCCs）不仅体积更小，而且具有更高的电容值。相应地，其所采用的介电材料必须同时满足高介电常数、晶粒尺寸小和严格的温度稳定性要求。然而，开发能够兼备这些特性的介电陶瓷仍然是该领域的一项关键技术瓶颈和研究空白。为了解决这一挑战，本研究通过精确的多离子掺杂和核壳结构比例控制，制备了近纳米级晶粒（晶粒尺寸约为 158.22nm，壳层结构约 10nm）的陶瓷，成功实现了温度稳定性上的突破（温度系数范围为-55℃~125℃，且在 25℃时电容变化率 ΔC/C25℃≤±1.97%，符合 X7C 规范）。与此同时，陶瓷表现出高介电常数（1418.4），满足现代 MLCC 对高容量的需求。此外，高绝缘电阻（I4.31×10^12 Ω·cm）和低介电损耗（0.60%）确保了漏电流引起的热损失最小化。陶瓷的出色能量存储稳定性及每单位电场下高能量密度（240 kV^-1·m^-2：W_rec/E 达到 131.25 J·kV^-1·m^-2）进一步保证了其在低至中等电场条件下的能量存储功能最大化及长期耐久性。该改性 BaTiO3 基陶瓷集高介电常数、细小晶粒尺寸和超稳定温度性能于一体，有望推动高精度高容量电路中的 MLCC 向小型化方向发展。

## 关键词

MLCCs，BaTiO3，多离子掺杂，核壳结构，温度超稳定性，近纳米级晶粒

## Abstract

In various high-precision systems, it is required that Multilayer Ceramic Capacitors (MLCCs) not only have smaller volumes but also higher capacitance values. Correspondingly, the dielectric materials used must simultaneously meet requirements for high permittivity (ε_r), small grain size, and strict temperature stability. However, the development of dielectric ceramics that fulfill all these properties remains a critical technical bottleneck and research gap in this field. To address this challenge, this work employs precise multi-ion doping and core-shell structure ratio control to prepare ceramics with near-nano grains (dg~158.22nm, with shell structure~10nm) successfully achieving breakthrough temperature stability (TCC: -55℃~125℃, ΔC/C25℃ ≤ ±1.97%, meeting the X7C specification). Simultaneously, ceramics exhibit high ε_r (1418.4) which aligns with the high capacity demands of modern MLCCs. Additionally, high insulation resistivity (Ir: 4.31 × 1012 Ω·cm) and low dielectric loss (tan δ=0.60%) ensure minimized thermal losses caused by leakage currents. The ceramics'excellent energy storage stability and high energy density per unit electric field (240 kV-1·m-2: Wrec /E reached 131.25 J·kV-1·m-2) further ensure their ability to maximize energy storage functionality under low-to-medium electric field conditions with long-term durability. The modified BaTiO3-based ceramics integrating high permittivity, small grain size, and temperature ultra-stability, hold promise for advancing MLCCs in high-precision circuits possessing high capacity and the potential for miniaturization.

## Keywords

MLCCs, BaTiO3, multi-ion doping, core-shell structure, ultra-stable, near-nano grains.

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