Advanced rare earth oxide doping ZrO2 based ceramic materials sintering behavior at lower temperature for solid oxide fuel cells

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Scandia-stabilized zirconia (ScSZ) is the electrolyte of choice for low- and mid-temperature SOFCs because Sc^{3+} matches Zr^{4+} in size, yielding high O^{2-} conductivity and a cubic fluorite structure. Yet between 500–650 °C the cubic phase transforms to the rhombohedral phase, causing abrupt conductivity loss and long-term aging. Co-doping with Yb_2O_3 widens the cubic stability window and redistributes oxygen vacancies via size matching, while adding Al_2O_3 and Bi_2O_3 enables low-temperature sintering. Al_2O_3 scavenges SiO_2 grain-boundary impurities and lowers boundary resistance, achieving 97.2 % density at 1350 °C; Bi_2O_3 forms a transient liquid phase that reduces shrinkage onset by ~200 °C and yields 97.1 % density. This "rare-earth + sintering-aid" synergy suppresses grain growth, cuts energy use, and retains 0.12 S cm^{-1} at 750 °C in 1Yb10ScSZ-0.3Al without forming low-conductivity second phases.