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## High-Entropy Fluorite Oxides

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### **Abstract (<150 words)**

Eleven fluorite oxides with five principal cations (in addition to a four-principal-cation ( $\text{Hf}_{0.25}\text{Zr}_{0.25}\text{Ce}_{0.25}\text{Y}_{0.25}\text{O}_{2-\delta}$ ) as a start point and baseline) were fabricated via high-energy ball milling, spark plasma sintering, and annealing in air. Eight of the compositions, namely ( $\text{Hf}_{0.25}\text{Zr}_{0.25}\text{Ce}_{0.25}\text{Y}_{0.25}\text{O}_{2-\delta}$ , ( $\text{Hf}_{0.25}\text{Zr}_{0.25}\text{Ce}_{0.25}\text{Y}_{0.125}\text{Yb}_{0.125}\text{O}_{2-\delta}$ , ( $\text{Hf}_{0.2}\text{Zr}_{0.2}\text{Ce}_{0.2}\text{Y}_{0.2}\text{Yb}_{0.2}\text{O}_{2-\delta}$ , ( $\text{Hf}_{0.25}\text{Zr}_{0.25}\text{Ce}_{0.25}\text{Y}_{0.125}\text{Ca}_{0.125}\text{O}_{2-\delta}$ , ( $\text{Hf}_{0.25}\text{Zr}_{0.25}\text{Ce}_{0.25}\text{Y}_{0.125}\text{Gd}_{0.125}\text{O}_{2-\delta}$ , ( $\text{Hf}_{0.2}\text{Zr}_{0.2}\text{Ce}_{0.2}\text{Y}_{0.2}\text{Gd}_{0.2}\text{O}_{2-\delta}$ , ( $\text{Hf}_{0.25}\text{Zr}_{0.25}\text{Ce}_{0.25}\text{Yb}_{0.125}\text{Gd}_{0.125}\text{O}_{2-\delta}$ , and ( $\text{Hf}_{0.2}\text{Zr}_{0.2}\text{Ce}_{0.2}\text{Yb}_{0.2}\text{Gd}_{0.2}\text{O}_{2-\delta}$ ), possess single-phase solid solutions of the fluorite crystal structure with high configurational entropies (on the cation sublattices), akin to those high-entropy alloys and ceramics reported in prior studies. Most high-entropy fluorite oxides (HEFOs), except for the two containing both Yb and Gd, can be sintered to high relative densities. These single-phase HEFOs exhibit lower electrical conductivities and comparable hardness (even with higher contents of softer components such as  $\text{Y}_2\text{O}_3$  and  $\text{Yb}_2\text{O}_3$ ), in comparison with 8 mol. %  $\text{Y}_2\text{O}_3$ -stabilized  $\text{ZrO}_2$  (8YSZ). Notably, these single-phase HEFOs possess lower thermal conductivities than that of 8YSZ, presumably due to high phonon scattering by multiple cations and strained lattices.

Keywords: high-entropy ceramic; fluorite oxide; thermal conductivity;  
hardness; sintering

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