Lead-free piezoceramics with improved temperature stability for precise actuators

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Piezoceramics are often used in sensor technology. Additionally, they can also function as actuators for positioning with nanometer precision, for example in lithography systems in semiconductor production, in high-resolution microscopy, or in biotechnology. Current well-established piezo ceramics use lead zirconate titanate. The synthesis, processing, and disposal of such lead-containing components is associated with risks to health and the environment. That is why strict regulations apply in the EU and worldwide, and their use is permitted only in exceptional cases.

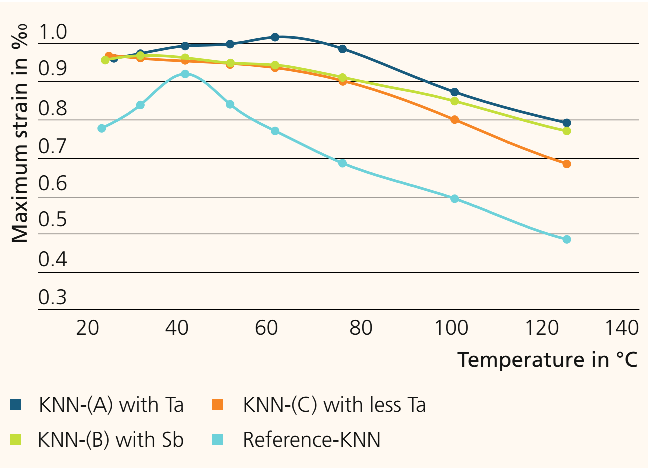

Fig. 1: Progression of strain with increasing temperature for complex doped KNN ceramics with applied field.

Fraunhofer IKTS is conducting research into lead-free alternative materials, together with PI Ceramic GmbH. The system (K,Na)NbO_3 (KNN) offers good properties as an actuator material: High strains in piezoceramics have been achieved in recent decades – an important prerequisite for the piezoeffect. However, the crystal structure of the developed KNN ceramics changes as the temperature increases. The ideal strain was initially only achieved within a small temperature interval around the structural change (Fig. 1). But stable strain behavior as temperatures change is essential for high-precision positioning systems. Through the targeted formation of solid solutions and optimized doping, the temperature range of the phase transition in the crystal system has now been significantly widened without a relevant reduction in piezoelectric strain. As a result of this work, several optimized materials with stable expansion behavior from room temperature to over 100 °C are now available (Fig. 1). This is a major step toward future positioning systems with lead-free piezo materials.

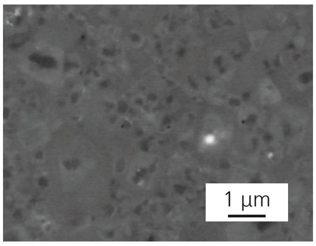

Fig. 2: Electron micrograph of a multiphase KNN structure.

Fig. 3: KNN ceramics as tablets for electrical characterization.

The developed KNN compositions have sintering temperatures of around 1200 °C. Reduced sintering temperatures were pursued for various reasons to establish KNN high-performance ceramics:

- Improved process control thanks to reduced evaporation of volatile components during sintering
- Lower energy consumption in the process
- Cost reduction through the ability to use cheaper metallizations for multilayer ceramics

To achieve these goals, various sintering aids were added, including CuO, ZnO, and Li_2CO_3. Most combinations of adapted KNN ceramics and sintering aids resulted in degradation. The maximum elongation in particular was significantly reduced. For this reason, each of the optimized materials requires a specially adapted combination with a sintering aid. In this way, the sintering temperature of the temperature-stable piezo materials can be reduced by up to 100 K while maintaining excellent strain properties. Future challenges include scaling up to larger sample sizes and the long-term stability of the new materials.

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