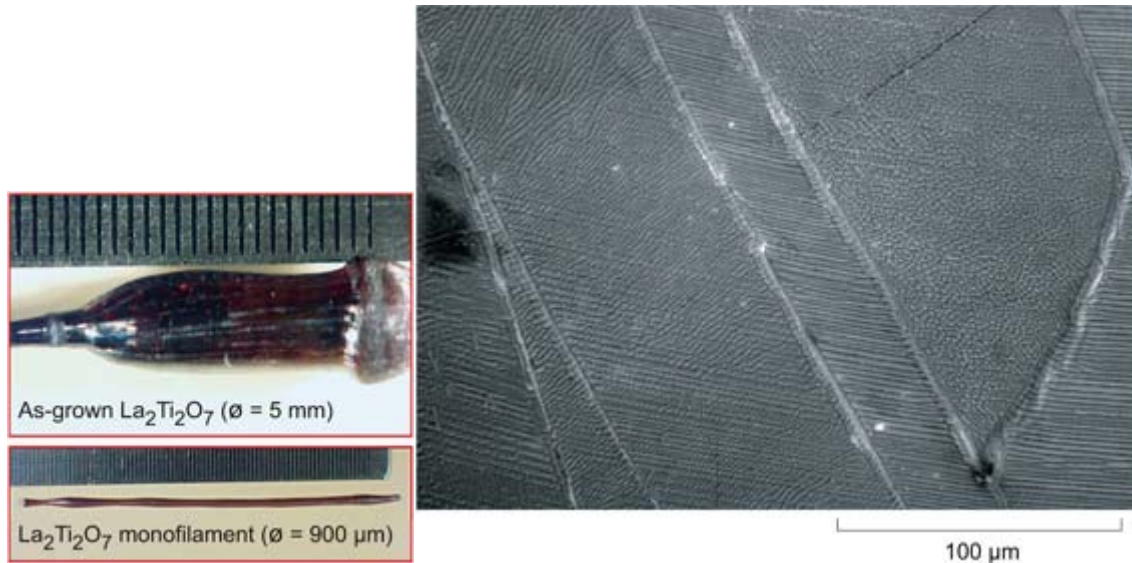


# High-Temperature Piezoelectric Ceramic Developed

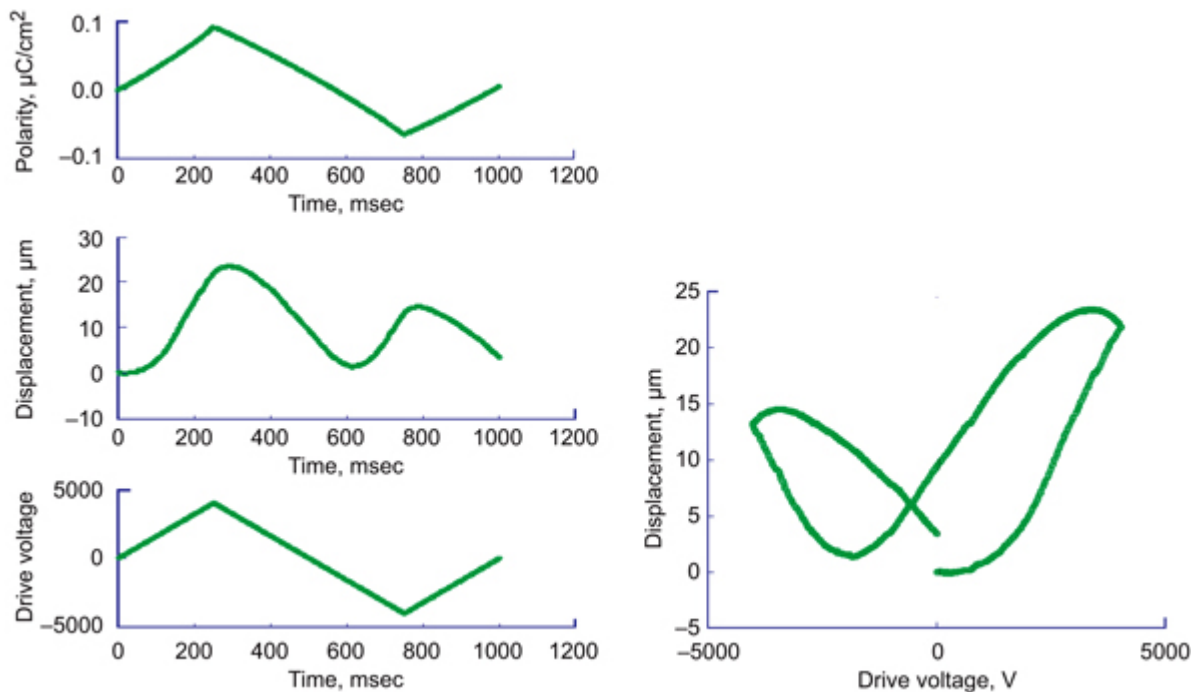
Active combustion control of spatial and temporal variations in the local fuel-to-air ratio is of considerable interest for suppressing combustion instabilities in lean gas turbine combustors and, thereby, achieving lower NO<sub>x</sub> levels. The actuator for fuel modulation in gas turbine combustors must meet several requirements: (1) bandwidth capability of 1000 Hz, (2) operating temperature compatible with the fuel temperature, which is in the vicinity of 400 °F, (3) stroke of ~4 mils (100 μm), and (4) force of 300 lb-force. Piezoelectric actuators offer the fastest response time (microsecond time constants) and can generate forces in excess of 2000 lb-force. The state-of-the-art piezoceramic material in industry today is Pb(Zr,Ti)O<sub>3</sub>, called PZT. This class of piezoelectric ceramic is currently used in diesel fuel injectors and in the development of high-response fuel-modulation valves. PZT materials are generally limited to operating temperatures of 250 °F, which is 150 °F lower than the desired operating temperature for gas turbine combustor fuel-modulation injection valves. Thus, there is a clear need to increase the operating temperature range of piezoceramic devices for active combustion control in gas turbine engines.



*Left: Different diameter high-temperature piezoelectric La<sub>2</sub>Ti<sub>2</sub>O<sub>7</sub> single crystals are grown. La<sub>2</sub>Ti<sub>2</sub>O<sub>7</sub> crystals in monofilament form are used for high-temperature composite fabrication. Larger diameter single crystals are used to produce textured bulk piezoelectric specimens. Right: Textured high-temperature piezoelectric La<sub>2</sub>Ti<sub>2</sub>O<sub>7</sub> successfully grown. Crystal habit is ~12° off [110] as determined by x-ray (not shown).*

Over the past year, substantial progress was made at the NASA Glenn Research Center in demonstrating the feasibility of high-temperature piezoelectric materials. A novel laser-melt process was developed for growing single-crystal fibers and rods of lanthanum-titanate (see the photograph on the left), and lanthanum titanate (La<sub>2</sub>Ti<sub>2</sub>O<sub>7</sub>) was

demonstrated to produce electrically actuated displacements one-quarter that of commercial lead-based piezoactuators. However, with a high-curie-temperature material (2600 °F), lanthanum titanate has the potential for displacement at temperatures where commercial PZT fails. In addition, we are developing a lower-cost method for texturing the polycrystalline material. (This yields about 80 percent of the single-crystal displacement but is much more amenable to commercial production.) This processing technique produces fully dense textured ceramics (see the photomicrograph on the right), eliminates grain boundary phases, and produces oriented low-energy interfaces. The textured piezoelectric ceramic structures ensure a high level of strain capability and a high degree of electromechanical coupling. Texture achieves much of the property benefits of single crystals, including greater success in polarization (domain alignment through application of high voltage, which enhances performance). This is of paramount importance with additional high-temperature piezoelectric ceramics systems of interest, such as bismuth perovskite and other systems of low crystal symmetry. Low crystal symmetry greatly increases the difficulty of polarization. The results shown in the following graphs are for an initial chemical formulation; refinements in composition and processing are expected to increase both the displacement and temperature capability. This work is an enabling technology for adaptive flow and combustion control concepts for intelligent propulsion systems.



*High-temperature piezoelectric  $\text{La}_2\text{Ti}_2\text{O}_7$ . Left: Time-dependent response of the drive voltage, displacement, and polarity. Right: Corresponding elongation and contraction of the 1-mm-thick ceramic element ( $\pm 4$  kV, 10 sec).*

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