Characterizing Novel Ternary and Doped Piezoelectric Single Crystals (2025)

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Abstract

Lead magnesium niobate – lead titanate (PMN-PT) based single crystals are high performance piezoelectric materials used in medical ultrasonic and underwater applications. Pure PMN-PT has exceptional piezoelectric properties with k33 of approximately 0.9 and d33 values ranging from 1100 to 1800 pm/V, however, the operating field and temperature range are limited by relatively low coercive field (EC = 2.5 kV/cm) and depoling temperature (TRT = 90-100 °C). Adding lead indium niobate as a ternary endmember (PIN-PMN-PT) is effective at increasing TRT (100-135 °C) and EC (4.5-7 kV/cm) with a small decrease in piezoelectric response. The upper limits to EC and TRT are achievable only with high PIN concentration (30% PIN or higher) which makes crystals more difficult to grow thus impacting yields. In this work two alternative systems are explored to determine their effectiveness at increasing TRT and EC without the need for high PIN concentration. The first system adds lead lutetium niobate as a ternary endmember (PLN-PMN-PT) and the other introduces Bi and Yb dopants to modify PIN-PMN-PT crystals. By introducing PLN to PMN-PT, EC can be increased to 4-5.6 kV/cm. No significant increase in TRT was observed in this system. By modifying PIN-PMN-PT with Yb, EC can be increased to 4.5-5.6 kV/cm which is 0.5 to 1kV/cm higher than undoped crystals. Similarly, TRT can be increased to 122 to 126 °C using Yb doping which is 7 to 10 °C higher than undoped crystals. By introducing Bi as an A-site dopant to PIN-PMN-PT d33 can be increased to a range of 1330 to 1600 pm/V, an increase of 200 to 300 pm/V compared to undoped crystal. Doping with Bi did not show improvement in EC or TRT. By co-doping with Bi and Yb crystals with improvements in d33, TRT, and EC can be designed. In co-doped crystals grown so far TRT ranges from 100 to 115 °C, EC ranges from 4.2 to 5.4 kV/cm and d33 ranges from 1000 to 1700 pm/V. Materials with higher Yb content typically exhibit higher TRT and EC, whereas materials with higher Bi content tend to trade off some of those improvements in favor of a higher d33. This allows some limited tunability of crystal properties for the specific application. Work is ongoing to determine the maximum property improvements possible in Bi and Yb co-doped PIN-PMN-PT single crystals.

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