High-Frequency Linear Array (20 MHz) based on Lead-Free BCTZ Crystal

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Background, Motivation and Objective

Due to health and environmental concerns, many countries have added piezoelectric lead-based compositions such as PZT to the list of hazardous substances. Currently three main families of lead-free piezoelectrics (KNN, BNT-BT, BCTZ) can compete with PZT for similar applications while single crystals should demonstrate better electromechanical properties than ceramics for medical imaging applications. In particular BCTZ single crystal may exhibit high piezoelectric constants of about 1500 pC/N-2000 pC/N [1]. This work proposes a complete study starting from the BCTZ material synthesis to the fabrication of high frequency ultrasonic probe which is characterized, integrated and evaluated on an imaging system.

Statement of Contribution/Methods

Centimeter-sized BaTiO3-based crystals were grown by top seeded solution growth from the BaTiO3−CaTiO3−BaZrO3 system [2]. Corresponding samples with $(110)_{pc}$ were oriented within 1° cut accuracy and poled at RT with an electric field of 1kV/mm. Two 1-3 piezocomposites with thicknesses of 270 and 78 micrometers were manufactured for resonant frequencies in air of 10 and 30 MHz respectively. For both cases, composites were designed to minimize the spurious effects of lateral vibrational modes by adjusting pitch and kerf values. The influence of piezoelectric pillar sizes was investigated through electromechanical performances. The dimensions of the piezocomposite at 30 MHz were sufficient to make a 128-element array with a 70 micron element pitch and a 1.5 mm elevation aperture. The transducer stack (backing, matching layers, lens and electrical components) was optimized to improve bandwidth and sensitivity. The probe was connected to a real-time HF 128-channel echographic system (Verasonics) for acoustic characterization (electroacoustic response, radiation pattern) and to acquire high-resolution in vivo images of human skin.

Results/Discussion

First electromechanical characterization of the BCTZ crystal plates and of the 10 MHz piezocomposite shows a thickness coupling factor of 40% and 50% respectively. Regarding the linear array the center frequency is 20 MHz and the fractional bandwidth at -6dB is 41%. A f-number of 2 and a focal distance of 6mm were chosen for the high-resolution images of human skin. These images were compared to those obtained with a lead-based 20-MHz commercial probe. Despite a significant difference in sensitivity between elements (around 20 dB in extreme cases) for BCTZ-based probe, in-vivo images demonstrate in a convincing way the potential of integration of this piezoelectric material in an industrial probe.

[1] H. Liu et al., “Large piezoelectric effect in Pb-free ceramics“, Phys. Rev. Lett., vol. 103, p. 257602, 2009.

[2] G. Buse et al., “Spinodal decomposition in lead-free piezoelectric BaTiO3-CaTiO3-BaZrO3 crystals“, Crystal Growth and Design, vol. 18 (10), pp 5874–5884, 2018.