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Holographic imaging of acoustic waves in piezoelectric ceramics by local electric field probes

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1. Introduction

Lead Zirconate Titanate $Pb(Zr_xTi_{1-x})O_3$ (PZT) has emerged as a highly effective piezo-electric ceramic material for generation and detection of ultrasound waves. It has a widespread use in ultrasonic transducers [1, 2]. PZT is considered to be an important material for ferroelectric thin films and has concerning applications, developed rapidly in recent years due to its potential for effective in excitation and detection of ultrasonic waves [3, 4]. PZT has a high piezoelectric coefficient and a high dielectric constant (typically 1700)[5-7].

PZT components manufactured from piezoelectric sintered materials exhibit isotropic and anisotropic behavior depending on manufacturing procedures. However, often during sintering and compaction processes in-homogeneities and anisotropy can be induced in the samples. The in-homogeneities of the grain orientation in the polycrystalline material can induce localized anisotropy in the ceramic. In anisotropic materials the velocity of the acoustic waves depends on the direction of propagation and orientation of the anisotropy. These features are monitored by imaging with the aid of scanned Coulomb excitation [8].

A local electrical field probe is used for excitation and detection of mechanical waves via piezo-coupling on a 1 mm thick PZT sintered piezo-ceramic plate. The transfer of electro-magnetic energy to acoustic energy by Coulomb coupling in piezoelectric materials is governed by the gradient of the electric field and the gradient of the piezoelectric properties. The electric field concentrated at the tip of the employed probes and the discontinuity of material properties at the surface lead to the highly localized excitation and detection in the employed Coulomb coupling scheme.

2. Experiments and Results

A similar experimental set-up as employed for the observation of the transport of acoustic waves has been reported previously [8].

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A short pulse with a duration of 25 ns, was delivered for excitation of acoustic waves in the PZT plate. During the scan, signals were picked up from the other side of the PZT plate with the aid of another localized probe identical to the exciting probe consisting of a steel sphere of 1.57 mm diameter. On the receiving side, a low noise pre-amplifier with suitably adjusted band pass was employed for signal conditioning prior to conversion to digital signals by a 100 MHz sampling rate transient recorder. The transient signals were acquired at 500×500 pixels distributed as a rectangular network over the 5×5 mm^2 scan area.

The evolution of acoustic waves in the 1 mm thick piezo-sintered ceramic is demonstrated in the images displayed in **Fig. 1.**

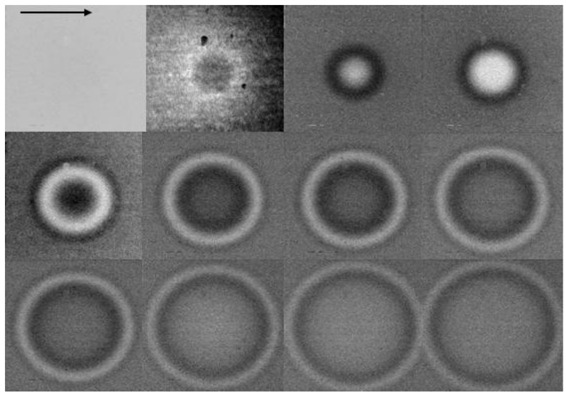

Fig. 1 Transient evolution of the amplitude of the propagating waves traveling in a 1 mm PZT ceramic disc. The time interval separating the displayed individual images is 870 ns. The image size is 5×5 mm^2

Each frame in **Fig. 1** corresponds to one of the successively recorded images. The brightness of the images represents the amplitude at the time of recording with medium gray relating to zero amplitude. The exciting local probe is located in the center of the images. Observed is dominantly a single rather short wave package traveling in radial direction. An analysis of the recorded data indicates that the dominantly observed waves travel with a velocity in the range of the expected velocity of longitudinal bulk waves. The normalized (to maximum) amplitude of the transient signal recorded at a position 50 µm away from the exciting electrode is displayed in **Fig. 2.** Multiple peaks correspond to the arrival of ultrasonic wave packets. For the largest signal to longitudinal polarized bulk waves, smaller contributions exhibiting velocities as to be expected for transversal polarized bulk waves. The delayed contributions relating to reflected and in part also mode converted signals. The first signal positioned at about 2.278 µs (**Fig. 2**) is, as indicated, due to electrical cross talk.

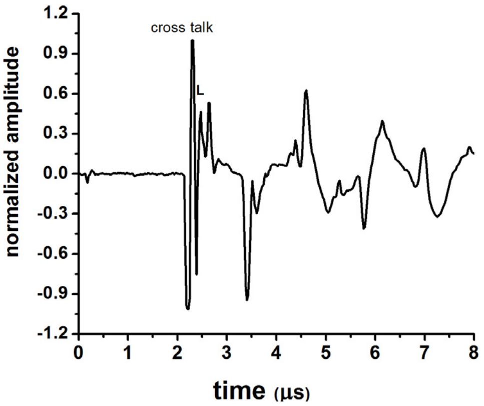

Fig. 2 Normalized transient signal amplitudes recorded with an electrode located on the opposite side of the PZT material

This cross talk indicates the time of excitation. The subsequent signal marked with L at a time of 2.476 µs is due to contributions from longitudinal polarized bulk acoustic waves. The later recorded peaks correspond to first and higher order echoes and finally contributions from subsequently developing guided wave modes. The difference between the time of excitation and the arrival of the first observed acoustic signal is 198 ns. For the recorded time dependent signal (**Fig. 2**) the excitation and detection is performed on opposing surfaces with a total travel distance of 1 mm. From the 1 mm path length and the observed travel time of 198 ns, a velocity of 1 mm /198 ns = 5050 m/s is determined comparing favorably with the expected velocity of longitudinal polarized bulk waves determined from listed typical material properties.

Concerning the resonances of bulk waves traveling normal to the sample surfaces the thickness of the PZT plate of 1 mm implies that the wavelength of the lowest resonance is 2 mm. The determined velocity of respective observed acoustic waves leads to a resonance frequency of the PZT disc of 2.525 MHz.

The wavelength is independently determined from the data as displayed in **Figs. 1** and **2** for the identified contributions relating to longitudinal polarized bulk waves. For that purpose the wavelength and group velocity of sound is determined from two orthogonal sections in the plane of the images. The respective wavelengths determined along the X and Y axes are 60 µm and 58 µm, respectively. The average diameter of particles is comparable to one hundredth of the wavelength suggesting the possibility of substantial Rayleigh scattering. The average group velocity of the acoustic waves relating to longitudinal polarization along the X and Y axes are 5390 m/s (± 1.6%) and 5214 m/s (± 1.2%), respectively. The density of the PZT piezo-sinter material has been determined as 7600 kg/m^3, which closely agrees with listed literature value [9].

3. Conclusions

The imaging of the propagation of longitudinal polarized acoustic waves in the piezoelectric-sintered ceramics is demonstrated with transducers consisting of localized electric field probes acting in combination with piezoelectric acousto-electric coupling by the direct and inverse piezo effect. The dominant contributions to the received signals are identified as longitudinal polarized bulk waves. The evolution of these waves that finally lead to the conversion to surface skimming and guided waves are observed here in the early stage concerning time and distance. The properties relevant for the transport of acoustic waves are determined and deviations from isotropic and homogeneous properties can be derived from the time sequential images recorded by Coulomb excitation and detection.

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