

Noncontacting Determination of the Piezoelectric Coefficient d_{33} of Lithium Tantalate up to 400 °C

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Summary:

In this work the laser Doppler vibrometry (LDV) is applied to determine the piezoelectric coefficients of sensor and actuator materials. LDV is a noncontacting optical method and, thus, not inhibiting sample oscillation allowing for highly precise material characterization. The piezoelectric constants are also directly evaluated from the measurement data. In this work d_{33} of lithium tantalate is determined up to 400 °C. However, in principle, the application temperature is limited by the furnace only in which the samples are installed.

Keywords: piezoelectric coefficient, laser Doppler vibrometry (LDV), lithium tantalate, non-contact measurement, high temperature sensorics

Introduction and Motivation

Piezoelectric materials are the basis of numerous applications, especially in sensor and actuator technology. Such applications require precise characterization of the piezoelectric properties of the materials used, even under demanding conditions.

Lithium tantalate (LiTaO₃, LT) is one such case: it has already proven to be a very good piezoelectric sensor material in acoustic sensor technology. In form of a solid solution with lithium niobate (LN), it is expected to be usable at elevated temperatures above 600 °C [1]. Consequently, these materials are of great interest to research and industry [2]. However, exploiting this potential at high temperatures includes high demands on the characterization of the piezoelectric properties of these materials.

Laser Doppler vibrometry (LDV) promises to meet these requirements. It allows the piezoelectric coefficient and the deflection at resonance to be measured independently of the temperature of the material. The measurement is contact-free and allows the material to vibrate almost completely freely.

Objective

The following work tests the functionality of this method by examining the piezoelectric properties of LT at different temperatures up to 400 °C. Later LDV shall be applied to similar materials such as the aforementioned LN and lithium niobate-tantalate solid solutions. Subsequently, measurements of the deflection during oscillation are examined and the piezoelectric coefficient is determined by these.

State of the Art – Measurements of the Piezoelectric Coefficient of Lithium Tantalate

There have already been several studies on the piezoelectric coefficient d_{33} of LT showing a broad range from 5.7–23.4 pm/V. A detailed list is provided in [3].

Most of these measurements were indirect: d_{xy} was calculated from measurements of the resonance and antiresonance frequency of the material in conjunction with other material constants, meaning that unknown influences may involuntarily been taken into account.

There are also a few direct measurements using piezoelectric d_{33} meters or piezoelectric force microscopy. The most comparable measurement to this work was performed using an optical heterodyne interferometer. In this case, however, there was no freely oscillating sample, but one that was firmly attached to a surface, requiring the use of a correction term to determine correct piezoelectric coefficients.

Laser Doppler Vibrometry

Z-oriented LT single crystalline discs (Precision Micro Optics, USA, thickness: 523 μm, diameter: 10 mm) are coated symmetrically with circular Pt electrodes (7 mm) by mesh printing and positioned in a furnace so that the whole electrode area oscillates freely.

A laser beam ($\lambda = 633$ nm) is directed at the electrode surface, reflected and then directed into the detector together with the reference beam. The detector signal, i.e., the phase shift of the laser beams, is forwarded to the decoder (OFV-5000, Polytec, Germany), which in turn forwards the measurement results to an oscillo-

scope (PicoScope 4824A, Pico Technology, UK), which also measures the excitation voltage. Details to the LDV setup used in this work are given in [3] and [4].

The LDV decoder translates this interference pattern into a time-resolved voltage signal that is converted into a frequency-resolved voltage signal using a fast Fourier transformation (FFT). The maximum deflection can then be determined from this [5] and is proportional to the measured deflection on the examined surface Δs in measuring direction (here: Z).

In the static case, i.e., far away from the resonant frequency, the piezoelectric coefficient d_{33} can be calculated by the quotient of deflection and excitation voltage U_{exc} (peak-to-peak voltage). This relation applies if, as here, mechanical / piezoelectric deflection and electrical excitation both point in the same direction.

In this work excitation voltages of 10 V_{pp} are used. At each temperature, the electrode surface is scanned using LDV. Two line scans (top-to-bottom and left-to-right) with equidistant 13 points each are performed. Five measured values per measuring point are averaged. The respective mean values of the deflections at all of these points are then used to calculate d_{33} .

Results and Discussion

The determined displacements are in the range of several hundred pm and, thus, still exhibit a signal-to-noise ratio of at least better than 5, mostly being in the range of 10 to 20.

Figure 1 shows the individual piezoelectric coefficients distributed over the surface of the sample. As predicted by theory, the deflection should be homogeneous over the entire surface and have no significant minima or maxima. The fact that this is confirmed in the experimental data verifies the approach in such a way that it does not influence the vibration behavior. The complete deflection without mechanical disturbances and, thus, also the correct undisturbed piezoelectric coefficient can be determined.

The mean values of d_{33} for each temperature are displayed in Figure 2. There is a slight increase in d_{33} over temperature, however, being small in relation to the statistical deviation.

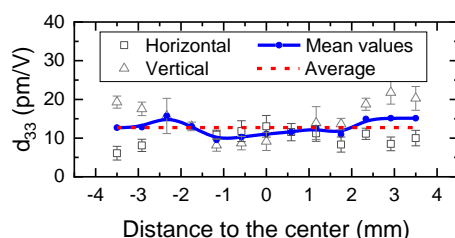


Fig. 1. Distribution and average of the piezoelectric coefficient d_{33} over the electrode surface in vertical and horizontal measuring direction at 200 °C.

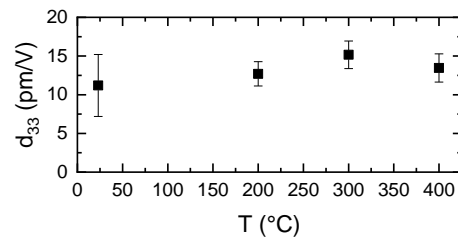


Fig. 2. Average values of d_{33} over the temperature. The errors correspond to the standard deviation of the spatial distribution (see Fig. 1).

Conclusions

The LDV is very well suited to measure the deflections of vibrating piezoelectric crystals. Deflections in the low two-digit picometer range are possible to detect. The measurement can be carried out over the entire surface of the crystal in order to create a surface profile. The holder setup used allows the measurement of free vibrations. It is worth mentioning that LDV has no upper limit to the working temperature. The limiting factor here is the furnace used.

For LT piezoelectric coefficients d_{33} of (12.67 ± 1.75) pm/V are determined. There are no clearly recognizable trends regarding the course of the piezoelectric excitation over the surface. The piezoelectric coefficients also do not appear to follow a recognizable trend over the temperature.

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