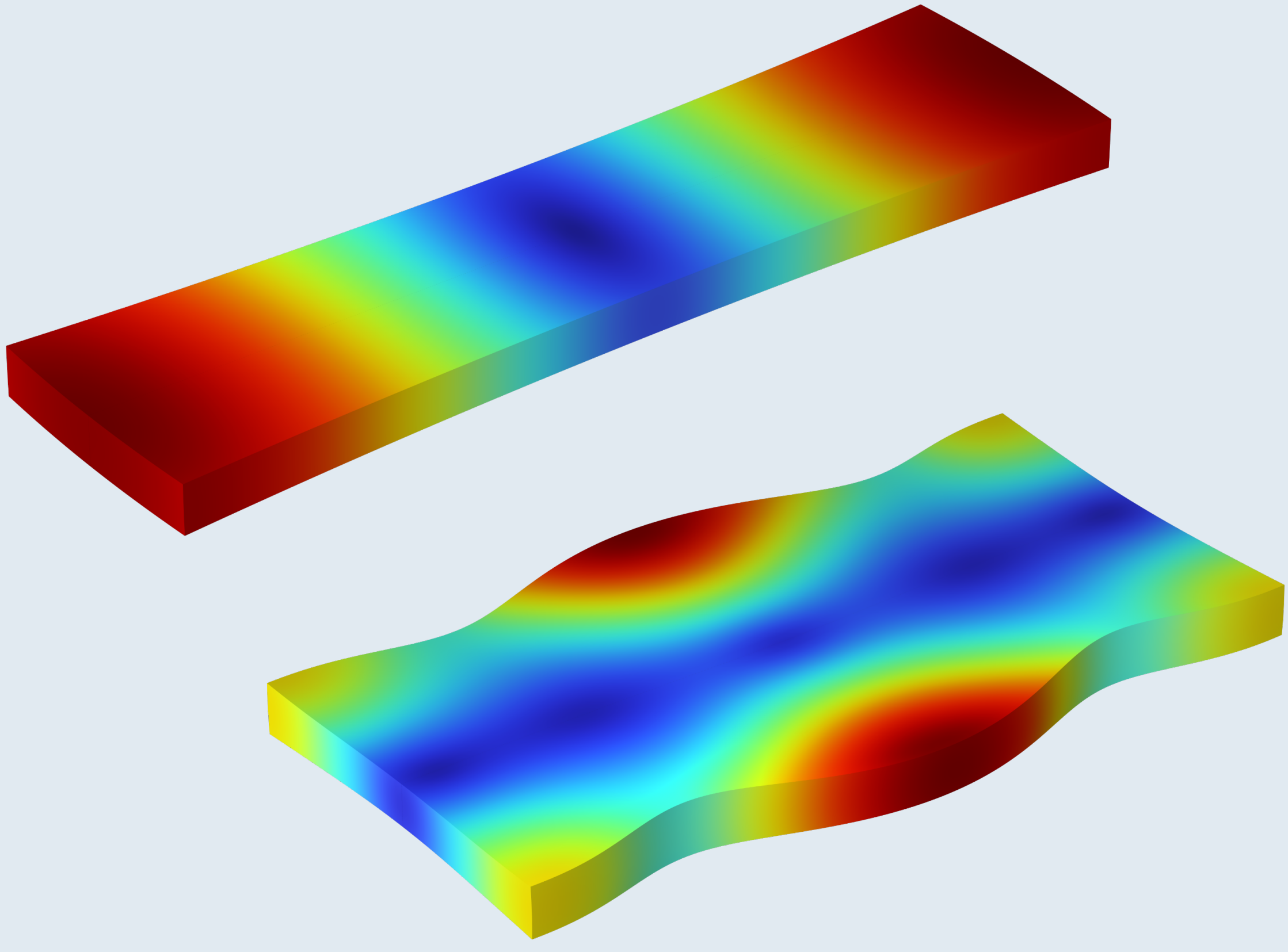




Determination of Piezoceramic Material Parameters

Inverse method for determining the material parameters of piezoceramics, combining measurement and simulation.

Michael Mayle¹, Axel Stürner¹, Roland Horn²

¹Applied Mathematics and Physics, Technische Hochschule Nürnberg Georg Simon Ohm, Germany

²Diehl Metering GmbH

Abstract

Identifying material parameters, particularly temperature-dependent ones, is often challenging, yet crucial for many simulation-based applications. In this contribution, we present first *preliminary* results of an inverse method for determining the material parameters of piezoceramics, combining measurement and simulation [1]. Cubic test samples with different polarizations serve as the basis for the identification process, with temperature-dependent impedance curves measured over the range 30°C to

150°C. These measurements, together with a corresponding COMSOL simulation, drive the parameter identification. The inverse method is formulated as an optimization problem in which the material parameters are the optimization variables and the objective is to reproduce a measured impedance curve. Two distinct vibrational resonances are used to constrain the identification.

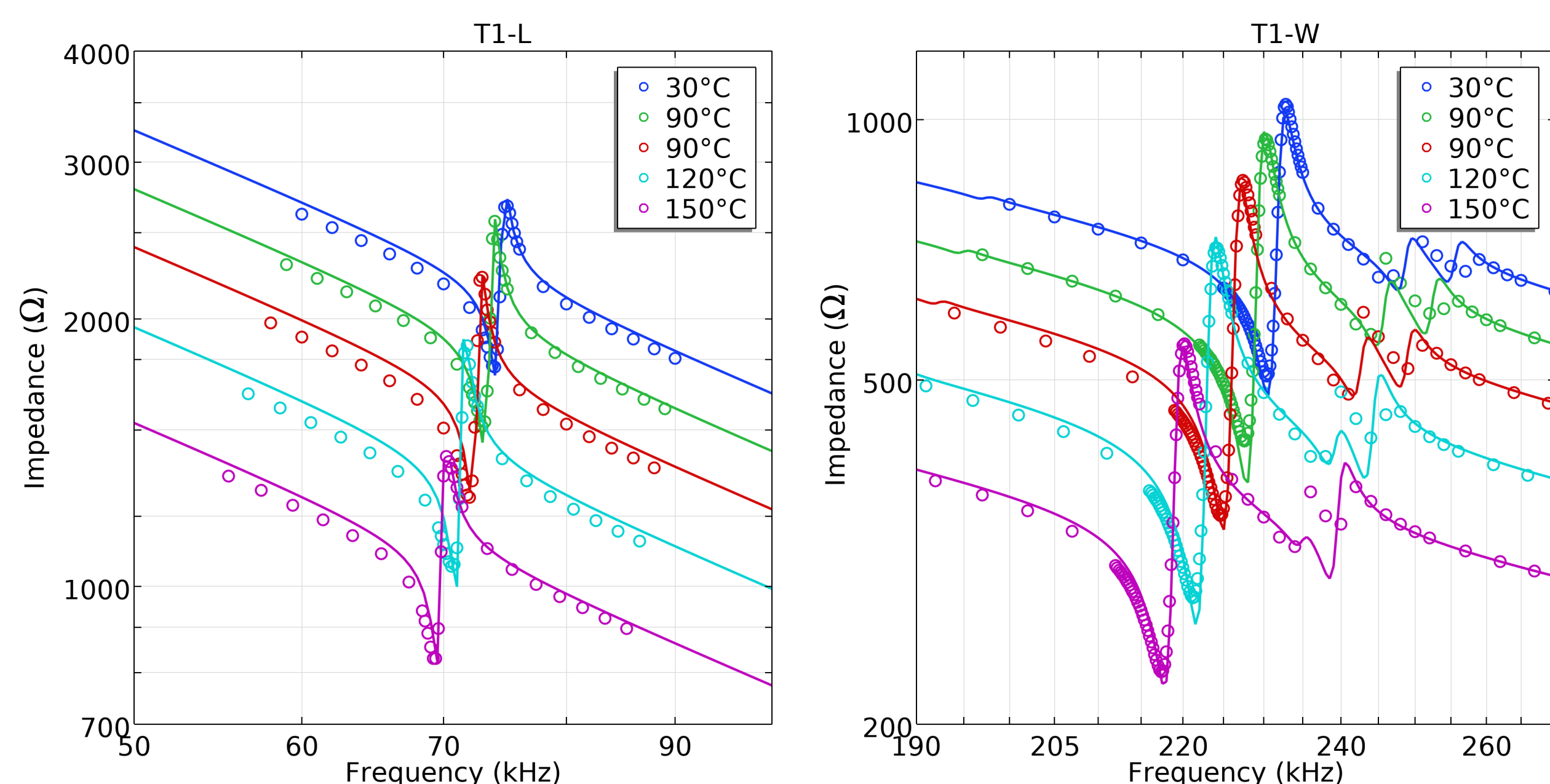


FIGURE 1. Temperature dependence of the T1-L and T1-W vibrational resonances of BNT piezoceramic test specimens. The solid lines are the simulation results after the inverse parameter identification while the measured impedances are represented by the circles and serve as experimental input for the *Parameter Estimation* study in COMSOL.

Methodology

The optimization routine for the inverse parameter identification is implemented in COMSOL using its *Parameter Estimation* feature. The workflow takes experimentally measured impedance spectra of two different vibrational resonances as an input, see Fig. 1 and title graphics. From a candidate set of material parameters – for this preliminary study we only take a subset of 7 from the 11 piezoelectric parameters – COMSOL calculates a simulated impedance spectrum. Its resonance features are compared with the measured data using a separate least-squares objective for each resonance; a higher density of frequency points is taken at the resonance peaks to give these features more weight. To minimize the objective function, the derivate-free *BOBYQA* algorithm iteratively adjusts the set of material parameters. When convergence is reached, the amplitude differences between the simulated and measured spectra reach a minimum, signaling the optimizer has converged toward the physical material properties.

Preliminary Results and Outlook

Figures 1 and 2 demonstrate that the inverse workflow can successfully reproduce the experimentally observed impedance behavior across different temperatures. Pronounced parameter changes show that explicitly accounting for temperature-dependent material behavior is essential.

The resonances chosen in this preliminary study are not sensitive to all material parameters. Therefore, a natural extension is to include differently polarized test samples with different parameter sensitivities [1]. This makes the workflow in COMSOL more troublesome: it prevents us from using a single *Parameter Estimation* study. Rather, post-processing of the simulated data becomes necessary. A possible way forward is to implement the optimization routine in Python using *MPh*, a Pythonic scripting interface to COMSOL Multiphysics®, while COMSOL is still used for the FEM simulation.

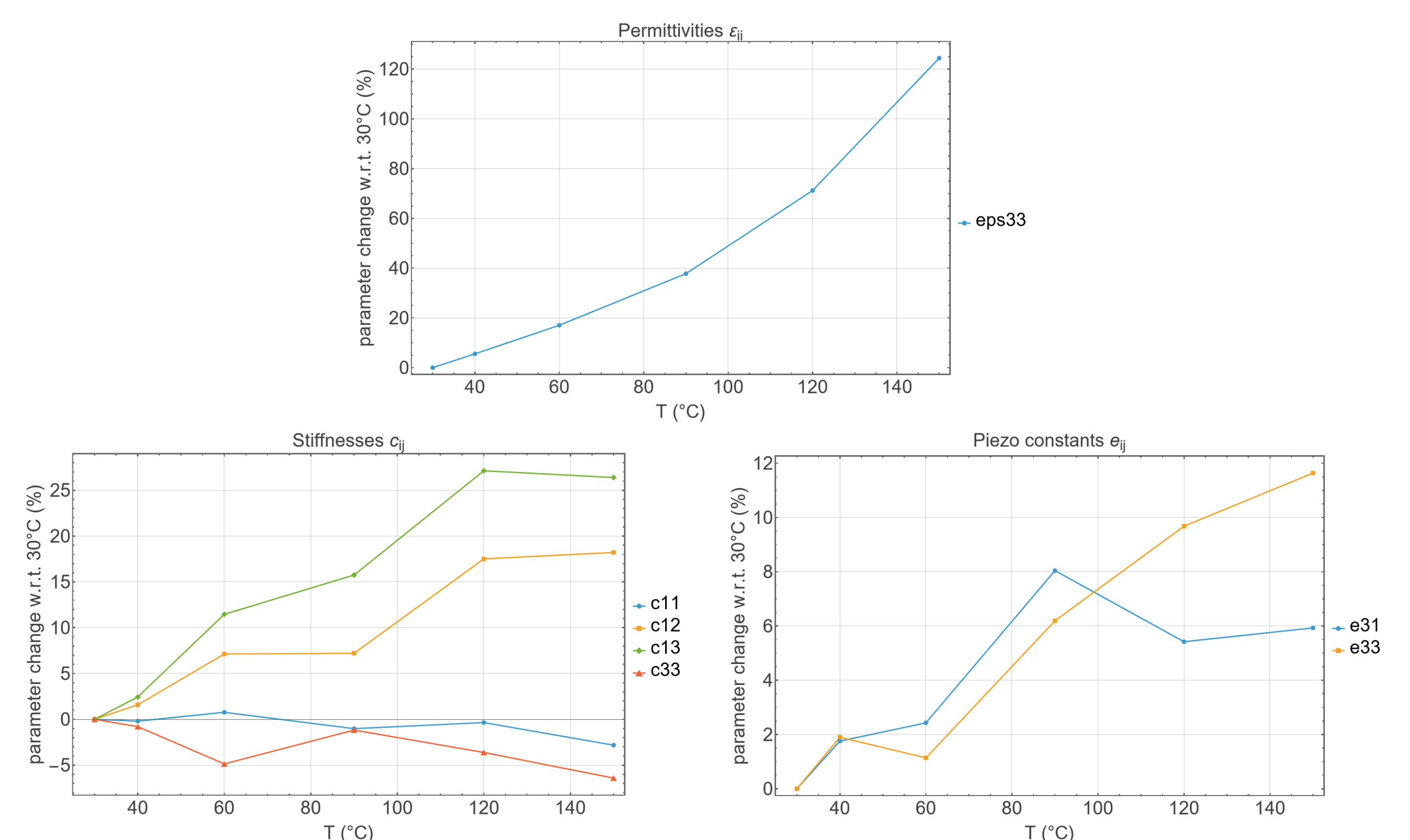
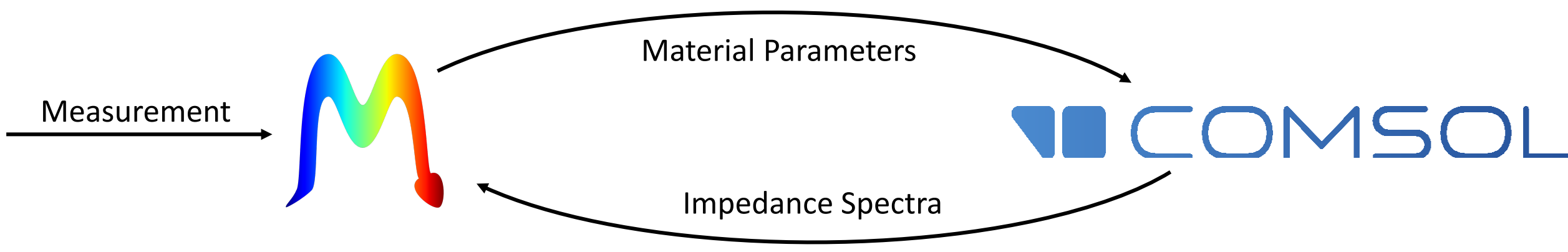
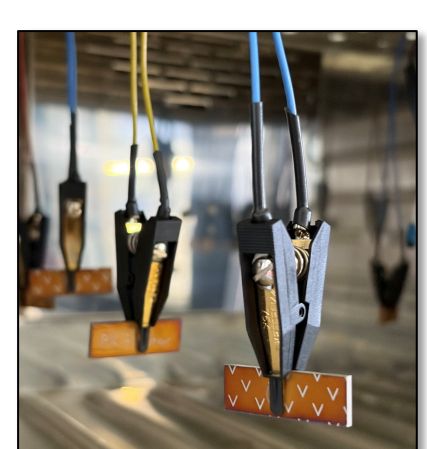


FIGURE 2. Temperature dependence of the piezoelectric material parameters which were selected for the inverse identification process.

REFERENCES

[1] S. J. Rupitsch and J. Ilg, Complete characterization of piezoceramic materials by means of two block-shaped test samples, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 62, 1403 (2015).