PRAP 3.1

Piezoelectric Resonance Analysis Program

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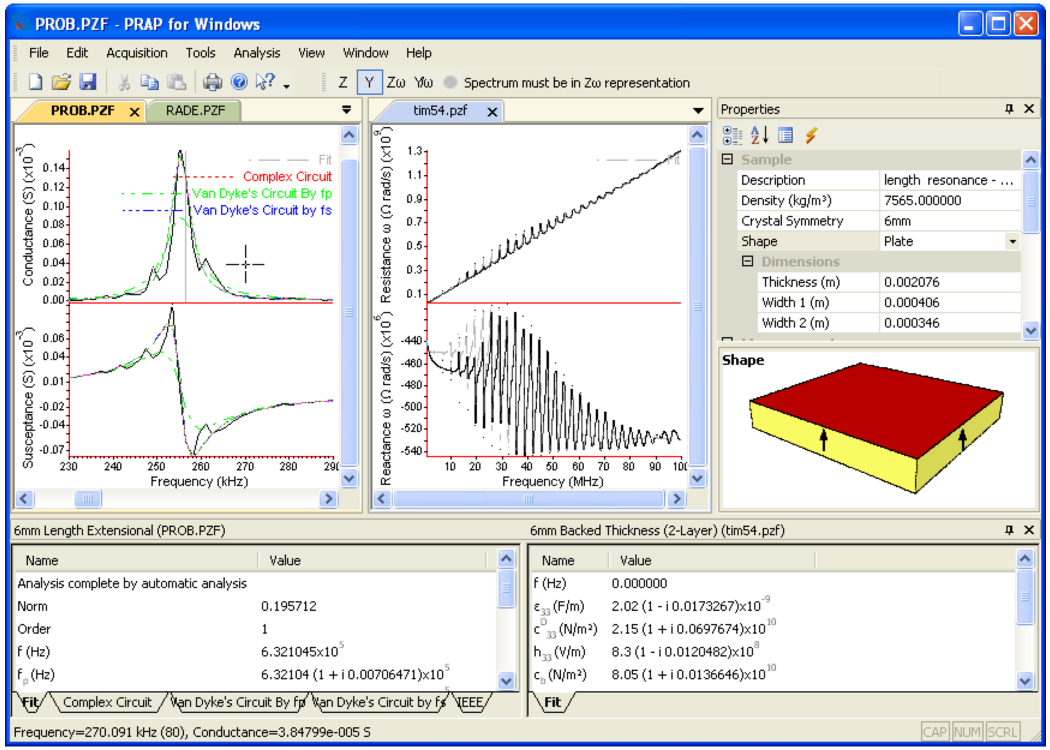
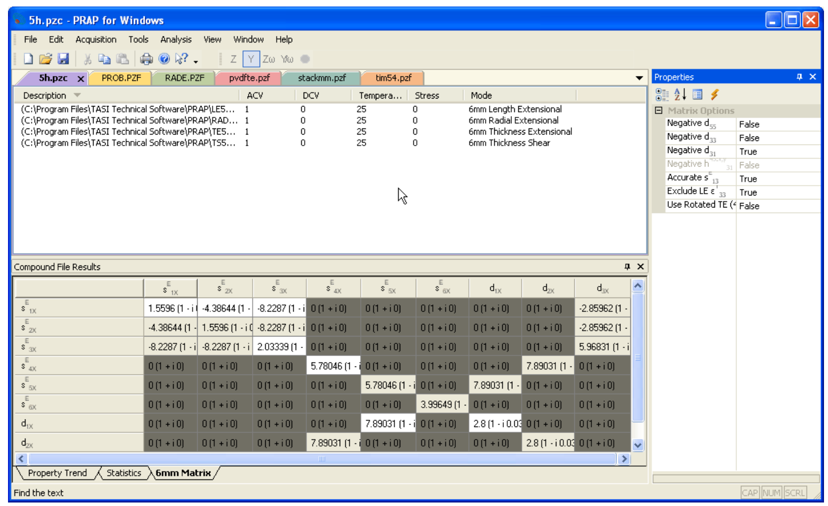
- Determine low field electrical, mechanical and electromechanical properties of piezoelectric materials from impedance frequency spectra
- Properties are complex with imaginary part representing losses
- Analysis of resonance harmonics allows determination of frequency-dependence in properties of a single sample
- Combining results from different modes allows determination of the complete reduced piezoelectric matrix
- Import or paste existing impedance spectra, or acquire new spectra directly from instrumentation
- Runs under all Microsoft Windows operating systems



Analysis

- Most analysis is point and click with many modes allowing fully automatic analysis
- As few as 3 points in a complex spectrum are required, not necessarily on-resonance, allowing highly localized analysis
- Non-linear regression allows average results for a range of frequency providing uncertainties in determined properties
- Results using method of the IEEE Standard on Piezoelectricity (ANSI/IEEE Std.176, 1987) are reported where appropriate
- Results include components for Van Dyke's and complex circuit models where appropriate
- Collective spectra can be used in a Compound File to determine;
  - ◊ statistical distribution of determined properties
  - ◊ frequency dependence of properties
  - ◊ with sufficient modes required for a given crystal symmetry, the complete reduced complex piezoelectric matrix



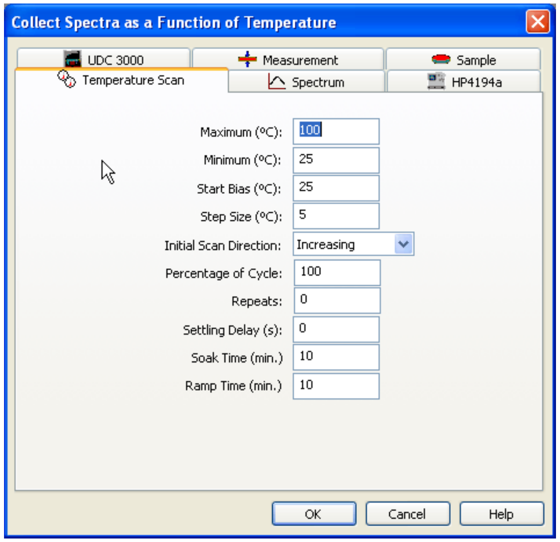
Analysis Modules

Resonance modes available depend on crystal symmetry and sample geometry. The following modes are available for analysis by PRAP:

6mm or C_{6v} or C_∞	Properties Determined
TE	$k_t, c^D_{33}, c^E_{33}, e_{33}, h_{33}, \varepsilon^S_{33}$
LE	$k_{33}, s^D_{33}, s^E_{33}, d_{33}, g_{33}, \varepsilon^T_{33}, \varepsilon^{S3=0}_{33}$
LTE	$k_{31}, s^E_{11}, d_{31}, g_{31}, \varepsilon^T_{33}$
TS	$k_{15}, c^D_{55}, c^E_{55}, s^D_{55}, s^E_{55}, e_{15}, h_{15}, d_{15}, g_{15}, \varepsilon^S_{11}, \varepsilon^T_{11}$
LS	$k_{15}, c^D_{55}, c^E_{55}, s^D_{55}, s^E_{55}, e_{15}, h_{15}, d_{15}, g_{15}, \varepsilon^S_{11}, \varepsilon^T_{11}$
Radial Extensional	$s^E_{11}, s^E_{12}, d_{31}, e^T_{33}, k^P, k_p, \varepsilon^P_{33}, \sigma, c^P_{11}, e^P_{31}, s^E_{66}, c^E_{66}$
Rotated (45°) TE	$k_t^{45:X,Y}, c_{33}^{D45:X,Y}, h_{33}^{45:X,Y}, \beta_{33}^{S45:X,Y}$
Stack LE	$k_{33eff}, s^D_{33eff}, s^E_{33eff}, d_{33eff}, g_{33eff}, \varepsilon^{S3=0}_{33eff}, \varepsilon^T_{33eff}, d_{33piezo}, \varepsilon^T_{33piezo}$, Stack Dissipation and Strain
Stack TE	$k_{teff}, c^D_{33eff}, c^E_{33eff}, e_{33eff}, h_{33eff}, \varepsilon^S_{33eff}, e_{33piezo}, \varepsilon^S_{33piezo}$, Stack Dissipation and Strain
2-Layer TE	$k_t, c^D_{33}, h_{33}, \varepsilon_{33}, c_b, Z_0, v_p, v_s$
3-Layer TE	$k_t, c^D_{33}, h_{33}, \varepsilon_{33}, c_b, c_f, Z_0, v_p, v_s, v_f$
Bimorph	$k_{31}, \varepsilon^T_{33}$, Flex Rigidity, EI
Sphere Breathing	$k_p, \varepsilon^T_{33}, s^E_c, d_{31}$
Ring Breathing	$k_{31}, \varepsilon^T_{33}, s^E_{11}, d_{31}$
Cylinder	$k_{31}, \varepsilon^T_{33}, s^E_{11}, s^E_{12}, d_{31}$

4mm or C_{4v}	Properties Determined
TE	$k_t, c^D_{33}, c^E_{33}, e_{33}, h_{33}, \varepsilon^S_{33}$
LE	$k_{33}, s^D_{33}, s^E_{33}, d_{33}, g_{33}, \varepsilon^T_{33}, \varepsilon^{S3=0}_{33}$
LTE	$k_{31}, s^E_{11}, d_{31}, g_{31}, \varepsilon^T_{33}$
TS	$k_{15}, c^D_{55}, c^E_{55}, s^D_{55}, s^E_{55}, e_{15}, h_{15}, d_{15}, g_{15}, \varepsilon^S_{11}, \varepsilon^T_{11}$
Rotated (45°) LTE	$k_{31eff}, s^{E45:Z}_{11}, d_{31}, g_{31}, \varepsilon^T_{33}$
Breathing	$N_s, N_{s^2p}, k, s, \varepsilon$

Acquisition

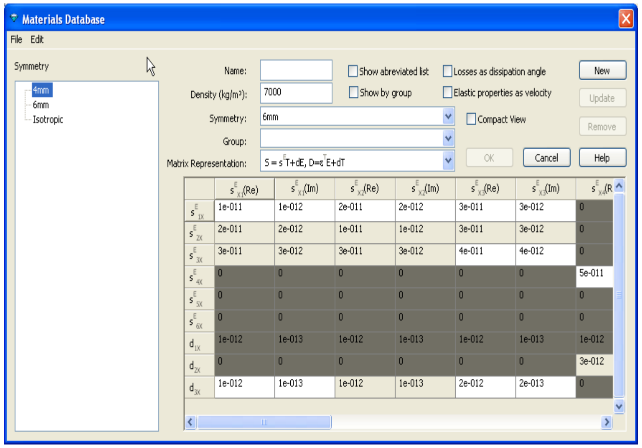


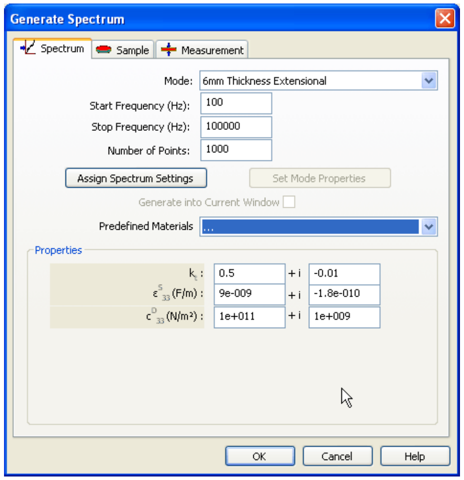
Direct acquisition from a variety of instruments is supported;

- including most impedance analyzers
- PRAP does not require accurate measurements at resonance meaning even low cost oscilloscopes or A/D cards could be used
- Temperature acquisition collects spectra as a function of temperature to determine temperature dependance of properties
- Time acquistion collects spectra as a function of time to determine aging of properties
- DC bias acquisition collects spectra as a function of DC bias to determine electrostrictive properties

Results

- Database of elements can be used to collate results for various materials
- Database of elements is available o modeling software such as Piezo1D
- Generate tool can generate resonance spectra from a set of material properties in any mode supported by PRAP





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