

# CALTRON PTE LTD

## Novocontrol Technologies GmbH

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PRODUCT OVERVIEW

Any product image or photo is for illustration purposes. Actual product may differ.

# **1. MATERIAL ANALYSIS TOOL DIELECTRIC, CONDUCTIVITY & IMPEDANCE SPECTROSCOPY**

## **INTRODUCTION**

# 1.1 SPECTROSCOPY INTRODUCTION

- **Dielectric, Conductivity and Electrochemical Impedance Spectroscopy** basically measure the impedance spectrum  $Z^*(\omega)$  of a sample material arranged between two or more electrodes. The sample material may be liquid or solid. The measured spectra are further evaluated by the following two research areas.
- **Dielectric Spectroscopy and Conductivity Spectroscopy:**
  - Main interest on materials properties; typically try to avoid contributions due to electrode effects. The intrinsic electric material properties (e.g. complex permittivity  $\epsilon^*(\omega)$  or conductivity  $\sigma^*(\omega)$  spectra) are easily evaluated from  $Z^*(\omega)$  with the known sample dimensions. The magnetic permeability spectra  $\mu^*(\omega)$  can be determined if the sample electrodes are replaced by an inductive coil filled with sample material.
  - Beyond frequency, electrical materials properties depend on additional parameters; the most important being temperature. Time, DC bias (superimposed static electrical field), AC field strength and pressure dependence are frequently determined as well. In this context, investigations on non-linear properties using field dependence and higher harmonics provide additional information.

# 1.1 SPECTROSCOPY INTRODUCTION

## ▪ **Electrochemical Impedance Spectroscopy (EIS):**

- An electrochemical technique that measures the impedance of a system (like an electrode or a material) at different frequencies by applying a small, alternating current (AC) signal and analyzing the resulting current response.
- Focus mostly on the properties of electrode/material interfaces. Electrodes are usually made of a metal; the materials are often electrolytes or ion conductors. Impedance spectra are typically taken **under controlled DC voltage (potentiostatic) or current (galvanostatic) conditions**.
- Both for material spectroscopy and EIS, the measured spectra are further processed with special procedures depending on the sample type. Generally, material specific models are matched by non linear curve fitting procedures to the measured data. As the models may include results from other material characterization methods, a link between the several techniques can be established in order to get more general information.
- Permittivity  $\epsilon^*(\omega)$ , conductivity  $\sigma^*(\omega)$  and permeability  $\mu^*(\omega)$  spectra are fundamental material parameters. With modern equipment, they can be accurately and automatically determined from mHz up to several GHz (15 decades) for almost all kind of materials. Sample preparation requires only little effort.
- Combination of these features make the methods of dielectric spectroscopy, conductivity spectroscopy, and electrochemical impedance spectroscopy both powerful and valuable tools, especially since electrical materials properties are of particular interest both for fundamental and application-oriented research. Although the principle of measurement is the same, researchers, materials, underlying theories, models and equipment requirements may differ.

## 1.2 APPLICATIONS

### ▪ **Dielectric, Conductivity, Impedance Spectroscopy and Material Analysis**

- Polymers, rubbers, glues, epoxies, liquid crystals, ferro electrics, ceramics, biological cells and polar liquids; Dielectric spectra, molecular relaxation and dynamics, glass transition
- Dielectric Analysis (DEA) of time-dependent processes; ageing and monitoring of chemical reactions, polymerization and epoxy curing processes.
- Pharmaceutical applications; characterization of drugs, drug distribution in the body, bio impedance
- Structural material properties; phase transitions, phase compositions and crystallization processes
- Semiconductors, organic crystals; charge transport, activation energy, charge mobility
- Sensor and LCD development
- Optical effects on charge transport
- Non-linear electric material effects (especially with Alpha-A high voltage test interfaces)
- Civil engineering; characterization of concrete

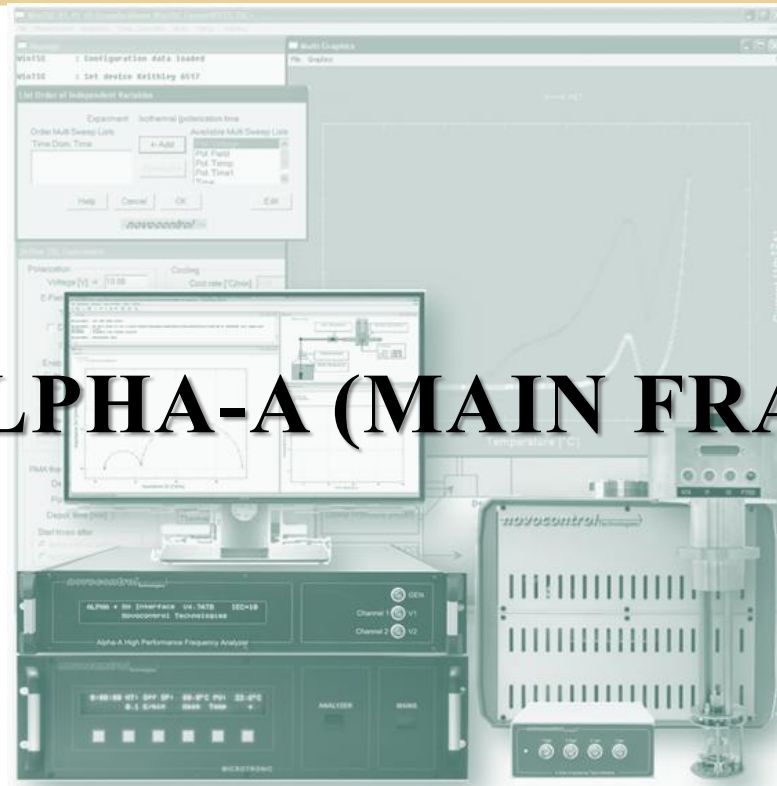
## 1.2 APPLICATIONS

- **Electrochemical Impedance Spectroscopy EIS (especially with Alpha-A electrochemical test interfaces)**
  - Ion and electron transport in electrolytes
  - Characterization of electrolyte metal interfaces and membranes
  - Fuel cells and battery research
  - Biological systems; organ and tissue studies
  - Characterization of corrosion impedance of paints and coatings; corrosion inhibitors
  
- **General Impedance Analysis**
  - Sensor, LCD and electronic component development
  - Quality control of insulators, electrical components, printed circuit boards, plastics, rubbers, liquids, paints, food, etc.

## 1.2 APPLICATIONS

- **High speed measurements for online monitoring of fast time variant processes**
  - One major area of dielectric, conductivity and electrochemical impedance spectroscopy is ***Monitoring Time Variant*** samples, which is usually due to **chemical reactions or crystallization**. Examples are time dependent measurements of e.g. epoxy curing or material ageing.
  - The Alpha-A mainframe has available **fast data rate option F** that can measure (and continuously send via the GPIB bus) **up to 600 impedance points per second**. This allows process monitoring on time scales below 1 ms.
  - The fast data rates are supported for all test interfaces, but is ***not available for all operation modes*** like e.g. reference measurement mode or at frequencies < 200 Hz.
  - For the mainframe standard version (without the option F) the maximum data rate is up to 10 data points per second.

## 2. ALPHA-A (MAIN FRAME)



## MODULAR SOLUTIONS

## 2.1 MODULAR CONCEPTS

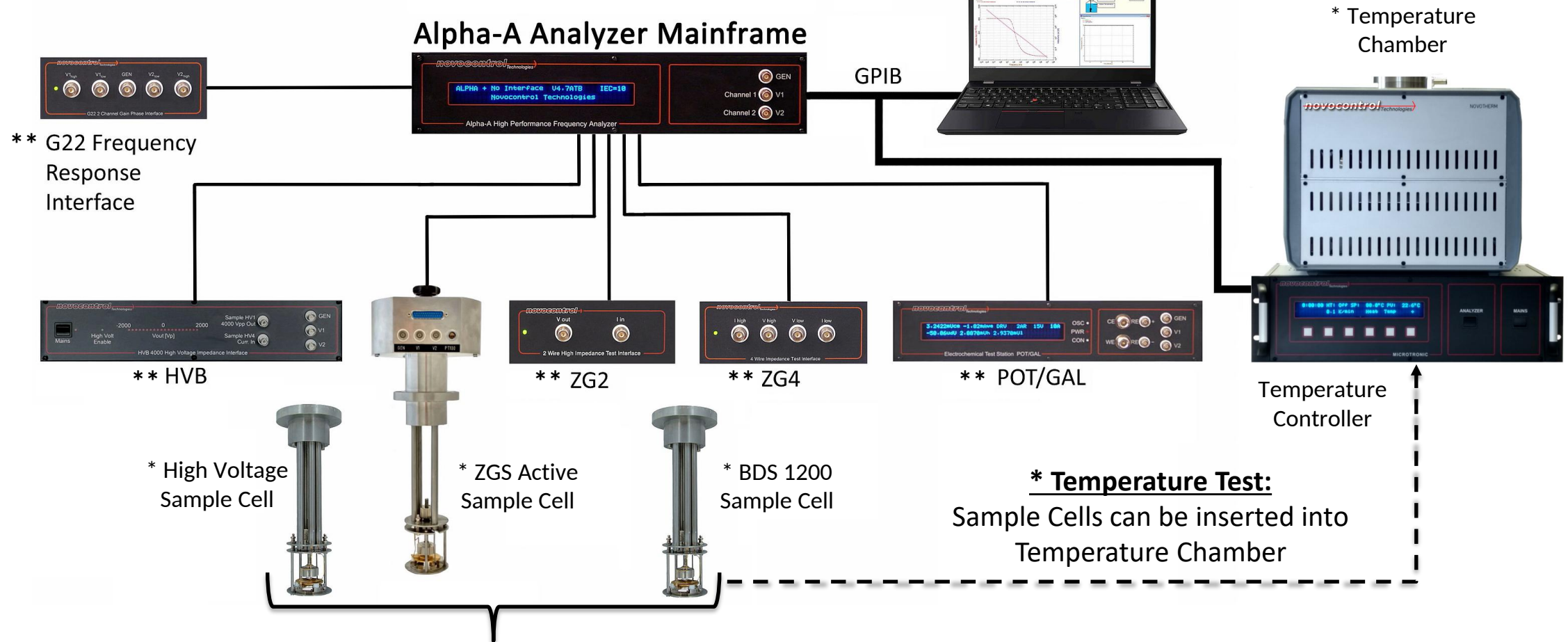
- **Modular Concepts** allow options to adapt the system according to requirements (ie start with basic system and extend the performance later on). Several modules for dielectric, conductivity and electrochemical impedance spectroscopy are available and can be operated as a standalone or combine with a temperature control system. All modules are controlled by **DETACHEM** software that also supports common impedance analyzers or LCR meters from other manufacturers.
- The **Alpha-A Modular Measurement System** for dielectric, conductivity and electrochemical impedance spectroscopy offers comparable accuracy, impedance range and flexibility over a broad frequency range from nearly DC up to 40 MHz range. These features are crucial for high quality materials characterization.
- The **Radio Frequency (RF) Option** can be extended to frequency range up to **3 GHz** for **Temperature-Controlled Electric (Permittivity,  $\epsilon$ ) and Magnetic Material Analysis (Permeability,  $\mu$ )**.
- **TurnKey Systems:** Customized system for dielectric, conductivity and electrochemical impedance spectroscopy can be configured upon request.

# 2.2 MODULAR SOLUTIONS: TYPICAL SETUP

**Figure 2.2-1: Typical Setup of Novocontrol Alpha-A Analyzer for Dielectric, Conductivity and Impedance Spectroscopy**

\*\* All **Test Interface modules** are applicable for use with Novocontrol Alpha-A Impedance Analyzers

PC with Novocontrol Software



**\* Temperature Test:**  
Sample Cells can be inserted into Temperature Chamber

## 2.2 MODULAR SOLUTIONS : TYPICAL SETUP

- Typical measurement setup comprises of the following components;
  - An **Impedance Analyzer** that measures the complex impedance  $Z(\omega)$  of the sample material over frequency, impedance range and ratio of  $Z(\omega)$  real and imaginary parts [quantified by the loss factor  $\tan(\delta)$ ],
  - **ZGX** Test interface modules depending on specific applications or measurement methods,
  - A **Sample Cell** able to make connection to the sample material and, or mount in a temperature control unit,
  - Optional **Temperature Control System** provides temperature variation during measurement with wide temperature range, fast stabilization time and minimal overshoot,
  - Computer with **Software Control, Evaluation and Analysis**.

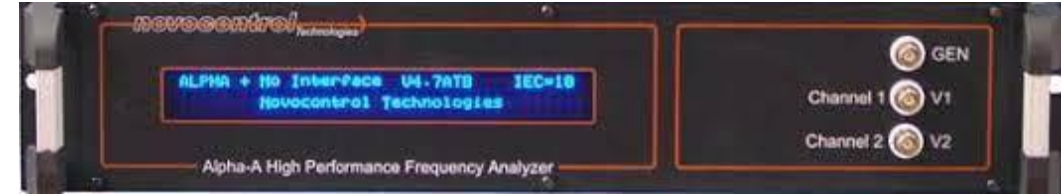
**Note:** For dielectric, conductivity and impedance measurements, an Alpha-A mainframe (Impedance Analyzer) has to be combined with at least one additional test interface.

## 2.2 MODULAR SOLUTIONS: TYPICAL SETUP

- **Novocontrol Modular Solutions** provide different *test interfaces* that allow optimization for specific application and yet provide high measurement accuracy with ultra wide impedance, broad frequency and temperature ranges
- Configuration for **2-, 3- or 4- wire** measurement mode provides wide impedance range and low loss factor resolution and accuracy
- Extended **High AC Voltage (HVB series)** and **High DC Current (POT/GAL series)** test interface modules are available for applications that include but not limited to;
  - ✓ Non-linear dielectric, conductivity and impedance spectroscopy,
  - ✓ Testing of materials under electrical stress conditions,
  - ✓ Analysis of high or low impedance materials
- Various **Sample Cells** (including liquid cells) for adapting different applications. All cells (except high temperature cell) are compatible with all the temperature control systems.
- **Temperature Control** extends the performance of dielectric- and impedance spectroscopy. Many key aspects of material properties such as molecular relaxations, conductivity, phase separation and transitions, activation energy, rate of blending, purity, ageing, curing and many others can be determined
- **Software** for control, data acquisition, data management and data analysis

## 2.3 MODULAR SOLUTIONS: ALPHA-A (MAINFRAME) ANALYZER

- Master unit for electric frequency domain measurements. For dielectric, conductivity and impedance spectroscopy the mainframe has to be operated in combination with one or more test interfaces
- Broad frequency range\*:  $3E10^{-5}Hz$  to  $4E10^7Hz$  include low frequencies for characterization of dielectric relaxations, electrochemical and high impedance effects
- Ultra wide impedance range:  $1E10^{-2}\Omega$  to  $1E10^{14}\Omega$  (covers range from conductors to insulators)
- Ultra wide capacitance range:  $1E10^{-15} F$  to  $1F$
- High phase and loss factor  $\tan(\delta)$  absolute accuracy:  $0.002^\circ$  and  $3E10^{-5}$  respectively for low loss dielectric materials and isolators broadband characterization
- **Automatic self calibration and diagnosis by user**; cancels long term internal drift and verifies functionality.
- Higher harmonics measurement over full frequency range for impedance and gain phase measurements for non linear electric response in materials or signals.
- Precision digital frequency response analyzer up to 40 MHz for two channel gain phase measurements with  $0.001^\circ$  phase and  $1E10^{-5}$  in amplitude resolution





## 2.3 MODULAR SOLUTIONS: ALPHA-A (MAINFRAME) ANALYZER

- \* **Frequency range Options;**
  - **Alpha-AL:** 3uHz to 300kHz
  - **Alpha-AK:** 3uHz to 3MHz
  - **Alpha-AN:** 3uHz to 20MHz
  - **Alpha-AT:** 3uHz to 40MHz
- **DC Bias Option B (on Alpha-A mainframe)** with ZG2 or ZG4 Test Interface:  $\pm 40V$ , 70mA
- **High Measurement Speed Option F:** Support measurement rates up to 600 impedance data points per second via GPIB port for online monitoring of fast time variant processes

## 2.4 MODULAR SOLUTIONS: ZG2 AND ZG4 TEST INTERFACES

- **Test Interface for Dielectric, Conductivity, Impedance and Gain Phase Measurements Options;** allow to locate interface module close to the sample, minimizing cable effects

TEST INTERFACE	FEATURES	GENERAL SPECIFICATION	REMARKS
<p><b>ZG2</b></p>  <p>The image shows the ZG2 test interface, a black rectangular module with two BNC connectors. The left connector is labeled 'V out' and the right is labeled 'I in'. A green LED is visible on the left side. The text '2 Wire High Impedance Test Interface' is printed at the bottom.</p>	<p>General purpose interface for 2-wire measurements of dielectric or conductive material samples with either</p> <ul style="list-style-type: none"> <li>▪ Novocontrol BDS 1200 parallel plate sample cell,</li> <li>▪ Customized sample cells,</li> <li>▪ Electronic components or materials.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Freq<sup>*[1]</sup>: 3μHz to 40 MHz</li> <li>▪ AC Out: 100uV to 3Vrms</li> <li>▪ VDC<sup>*[2]</sup>: ±40, 70 mA</li> <li>▪ Output Impedance: 50 Ω</li> <li>▪ Input Impedance: 10<sup>14</sup> Ω</li> </ul>	<ul style="list-style-type: none"> <li>▪ Max AC output dependent on selected frequency</li> </ul> <p>*[1] Dependent on selected frequency option for Alpha-A</p> <p>*[2] Require DC Bias Option B on Alpha-A</p>
<p><b>ZG4</b></p>  <p>The image shows the ZG4 test interface, a black rectangular module with four BNC connectors. From left to right, they are labeled 'I high', 'V high', 'V low', and 'I low'. A green LED is visible on the left side. The text '4 Wire Impedance Test Interface' is printed at the bottom.</p>	<ul style="list-style-type: none"> <li>▪ Selectable 2-, 3- or 4-wire measurement</li> <li>▪ Configurable with additional high input impedance and driven shielded V<sub>high</sub> and V<sub>low</sub> differential voltage inputs</li> <li>▪ Applicable for low impedance samples below 1 Ω (eg. strong electrolytes, heavily doped semiconductors, metals, superconductors)</li> </ul>	<ul style="list-style-type: none"> <li>▪ Freq<sup>*[1]</sup>: 3μHz to 40 MHz</li> <li>▪ AC Out: 100uV to 3Vrms</li> <li>▪ VDC<sup>*[2]</sup>: ±40, 70 mA</li> <li>▪ Output Impedance: 50 Ω</li> <li>▪ Input Impedance: 10<sup>14</sup> Ω</li> <li>▪ Input Impedance with driven shield: 10<sup>12</sup> Ω   10pF</li> </ul>	<ul style="list-style-type: none"> <li>▪ Max AC output dependent on selected frequency</li> </ul> <p>*[1] Dependent on selected frequency option for Alpha-A</p> <p>*[2] Require DC Bias Option B on Alpha-A</p>

## 2.5 MODULAR SOLUTIONS: G22 TEST INTERFACE

- **Test Interface for two channel frequency response, gain phase measurements with differential input channels for the Alpha-A Modular Measurement System**
- For general purpose frequency response or gain phase measurements
- Not to be used for dielectric, conductivity or impedance measurements
- Measures amplitudes and phase shift  $V1_{high}-V1_{low}$  and  $V2_{high}-V2_{low}$  of two voltage channels
- Has similar functionality to a dual input channel lock-in amplifier with improved accuracy and extended frequency range
- Frequency: 3  $\mu$ Hz to 20 MHz (Applicable for Alpha-AN and Alpha-AT only)
- AC Signal Out: 100  $\mu$ V to 3 Vrms
- DC Bias Out:  $\pm 40$ V, 70mA (Require DC Bias option B on Alpha-A mainframe)
- Input Impedance:  $10^{12}\Omega$  | 10pF



## 2.6 MODULAR SOLUTIONS: HIGH VOLTAGE (HVB) TEST INTERFACE

- **High Voltage Test Interface for Dielectric, Conductivity and Impedance Two-Electrode Spectroscopy for the Alpha-A Modular Measurement System Options;** test interface extension for dielectric, conductivity, impedance 2 electrode spectroscopy with DC and/or AC voltages from  $\pm 150\text{Vp}$  to  $\pm 2\text{kVp}$
- Optimized for Broadband High Voltage Measurements of Low Loss Dielectrics
- For dielectrics, semiconductors or electronic components at high AC and/or DC voltages, such as;
  - Non linear dielectric/impedance spectroscopy,
  - Characterization of materials or components under stress,
  - Extreme high impedance samples exceeding  $10^{14} \Omega$
- High AC output voltage with protection against permanent shorts
- For material measurements, Novocontrol **High Voltage Sample Cell (BDS 1200HV)** is recommended



PARAMETERS	HVB-300	HVB-1000	HVB-4000
FREQUENCY	3 $\mu$ Hz to 1MHz <sup>*[1]</sup>	3 $\mu$ Hz to 10kHz	3 $\mu$ Hz to 10kHz
AC OUT	150Vp, 70mA <sup>*[2]</sup>	500Vp, 3.3mA <sup>*[2]</sup>	2kVp, 2.7mA <sup>*[2]</sup>
VDC OUT	$\pm 150\text{V}$ , 70mA <sup>*[2,3]</sup>	$\pm 500\text{V}$ , 3.3mA <sup>*[2,3]</sup>	$\pm 2\text{kV}$ , 2.7mA <sup>*[2,3]</sup>
OUTPUT IMPEDANCE	200 $\Omega$	150k $\Omega$	750k $\Omega$

[1] Require Alpha-A Mainframe Option AK or AN or AT

[2] AC + DC Voltage peak must not exceed VCD OUT

[3] Require Alpha-A Mainframe DC Bias option B

## 2.7 MODULAR SOLUTIONS: HIGH CURRENT (POT/GAL) TEST INTERFACE

- **Test Interfaces for Electrochemical Impedance Spectroscopy (EIS), Dielectric, Conductivity, 2-, 3- and 4-Electrodes Spectroscopy and Gain Phase Measurements Options;** test interface extension for Electrochemical applications with fast potentiostat and galvanostat control loops for defined dc voltage and current cell polarization control which can be superimposed by an AC signal for EIS application, features;
  - 2-,3- or 4- wire configuration
  - Supports non-linear EIS by higher harmonic measurements
  - 4-CH, 24-bit digitizer for simultaneous DC signal measurements of the counter-, 2 reference- and working electrodes
  - Automatic DC level shifters at the working and reference electrodes inputs; compensate DC voltage and current offsets to accurately measure small superimposed AC signals for EIS
  - For sample protection, the high-power counter electrode signal output supports fast voltage and current limiters independent of the main control loop. Both voltage and current limits are continuously adjustable and operate simultaneously both in potentiostat and galvanostat modes
  - Supports real-time measurements by up to 150 impedance data points / second (option) and 1,500 voltage current data points / second in time domain mode
  - Direct voltage mode; In this mode, the POT/GAL interfaces can be used for general purpose dielectric, conductivity and impedance spectroscopy with extended output signal amplitude range




## 2.7 MODULAR SOLUTIONS: HIGH CURRENT (POT/GAL) TEST INTERFACE

PARAMETER	POT/GAL 15V-10A	POT/GAL 30V-2A
<b>COUNTER ELECTRODE POLARIZATION</b>	<ul style="list-style-type: none"> <li>▪ Voltage: <math>\pm 15\text{Vp}</math> DC and/or AC</li> <li>▪ Current: <math>\pm 10\text{A}</math> DC and/or AC</li> <li>▪ Max. Output Power: 120W</li> <li>▪ Continuously Adjustable Simultaneous Voltage and Current Limits: 0.5V to 20V / 1mA to 10A</li> </ul>	<ul style="list-style-type: none"> <li>▪ Voltage: <math>\pm 30\text{Vp}</math> DC and/or AC</li> <li>▪ Current: <math>\pm 2\text{A}</math> DC and/or AC</li> <li>▪ Max. Output Power: 60W</li> <li>▪ Continuously Adjustable Simultaneous Voltage and Current Limits: 1V to 40V / 2mA to 2A</li> </ul>
<b>REFERENCE VOLTAGE INPUTS</b> Single or differential configuration with selectable driven shields	<ul style="list-style-type: none"> <li>▪ Range: <math>\pm 15\text{Vp}</math>, 10<math>\mu\text{V}</math> resolution</li> <li>▪ Input impedance: <math>&gt; 10^{12}\Omega</math>   10pF</li> <li>▪ Bandwidth: DC to 10MHz</li> </ul>	<ul style="list-style-type: none"> <li>▪ Range: <math>\pm 30\text{Vp}</math>, 20<math>\mu\text{V}</math> resolution</li> <li>▪ Input impedance: <math>&gt; 10^{12}\Omega</math>   10pF</li> <li>▪ Bandwidth: DC to 10MHz</li> </ul>
<b>WORKING ELECTRODE CURRENT INPUT</b>	<ul style="list-style-type: none"> <li>▪ Range: 100pA to 10A</li> <li>▪ Resolution: <math>10^{-5}</math> of range, 0.1pA min.</li> <li>▪ Bandwidth: DC to 10MHz</li> </ul>	<ul style="list-style-type: none"> <li>▪ Range: 20pA to 2A</li> <li>▪ Resolution: <math>10^{-5}</math> of range, 0.1pA min.</li> <li>▪ Bandwidth: DC to 10MHz</li> </ul>
<b>IMPEDANCE MEASUREMENT</b>	<ul style="list-style-type: none"> <li>▪ Frequency Range<sup>[1]</sup>: 3<math>\mu\text{Hz}</math> to 1MHz</li> <li>▪ Impedance Range: <math>10^{-4}\Omega</math> to <math>10^{13}\Omega</math></li> <li>▪ Phase Accuracy/Resolution: <math>&lt; 6\text{m}^\circ/0.6\text{m}^\circ</math></li> <li>▪ <math>\tan(\delta)</math> Accuracy/Resolution: <math>&lt; 10^{-4}/&lt; 10^{-5}</math></li> </ul>	<ul style="list-style-type: none"> <li>▪ Frequency Range<sup>[1]</sup>: 3<math>\mu\text{Hz}</math> to 1MHz</li> <li>▪ Impedance Range: <math>10^{-4}\Omega</math> to <math>10^{13}\Omega</math></li> <li>▪ Phase Accuracy/Resolution: <math>&lt; 6\text{m}^\circ/0.6\text{m}^\circ</math></li> <li>▪ <math>\tan(\delta)</math> Accuracy/Resolution: <math>&lt; 10^{-4}/&lt; 10^{-5}</math></li> </ul>

[1] Applicable for Alpha-A with option AK, AN or AT only

## 2.8 MODULAR SOLUTIONS: SAMPLE CELL, BDS 1200/BDS 1200HV


SAMPLE CELL	FEATURES	GENERAL SPECIFICATION	REMARKS
<p><b>BDS 1200</b> <b>BDS 1200HV (High Voltage)</b></p> 	<ul style="list-style-type: none"> <li>▪ Standard sample cell for dielectric, conductivity, and electrochemical impedance measurements</li> <li>▪ Integrated Pt100 temperature sensor near sample</li> <li>▪ Stainless steel construction</li> <li>▪ Gold plated electrodes (available in 10, 20, 30 and 40 mm diameter)</li> <li>▪ 2- or 4-wire connection to any impedance analyzer via BNC connectors</li> <li>▪ Easy to use sample mounting mechanism. Sample material is prepared between two parallel electrodes as a sandwich capacitor.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Frequency: DC to 10MHz</li> <li>▪ Temperature: -200 °C to 400 °C</li> <li>▪ Sample <math>\varnothing</math>: 40mm max.</li> <li>▪ Sample Thickness: 50um to 15mm</li> </ul> <p><b>Applicable Measurements</b></p> <ul style="list-style-type: none"> <li>▪ Electrical characterization of materials (solids/liquids/powder) in parallel-plate configuration</li> <li>▪ Electrical characterization of liquids on InterDigitated Electrodes, BDS 1420 (IDE)</li> <li>▪ Dielectric Spectroscopy</li> <li>▪ Conductivity Spectroscopy</li> <li>▪ Electrochemical Impedance Spectroscopy</li> </ul>	<p><b>Extensible by liquids cells;</b></p> <ul style="list-style-type: none"> <li>▪ BDS1307, cylindrical cell for liquids</li> <li>▪ BDS1308, parallel plate cell for liquids</li> <li>▪ BDS1309, parallel plate cell for liquids with high permittivity/conduction</li> </ul> <p><b>Supported Analyzers &amp; Test Interfaces;</b></p> <ul style="list-style-type: none"> <li>▪ Alpha-A + ZG2 (2-wire)</li> <li>▪ Alpha-A + ZG4 (4-wire)</li> <li>▪ Alpha-A + POT/GAL 30 V/2A</li> <li>▪ Alpha-A + POT/GAL 15 V/10A</li> <li>▪ NEISYS</li> </ul> <p><b>Supported Temperature Controller;</b></p> <ul style="list-style-type: none"> <li>▪ Quatro Cryosystem: -160 °C to 400 °C</li> <li>▪ Novocool: -100 °C to 250 °C</li> <li>▪ Novotherm: ambient to 400 °C</li> </ul>

## 2.9 MODULAR SOLUTIONS: ACTIVE SAMPLE CELL, ZGS

- **Test Interface with Active Sample Cell for Dielectric, Conductivity, Impedance Two-Electrode Spectroscopy for the Alpha-A Modular Measurement System**
- Same functionality as the ZG2 interface, but is integrated with a two parallel plate electrode sample cell similar to the passive BDS 1200 cell. Avoids cables in the impedance path between the sample electrodes and analyzer input terminals
- Has a Pt100 temperature sensor at the sample and can be operated in combination with one of the Novocontrol temperature control systems between  $-160^{\circ}\text{C}$  to  $400^{\circ}\text{C}$ .
- Arrangement is easy to use and allows flexible sample preparation; optimal turnkey solution for dielectric, conductivity and impedance material measurements between two parallel plate electrodes not requiring 3- or 4-wire configurations
- ZGS is specified at the sample electrodes position and hence minimize artifacts due to cell contributions
  - **Freq:**  $3\mu\text{Hz}$  to 40 MHz (Dependent on selected frequency option for Alpha-A Mainframe)
  - **AC Out:** 100uV to 3Vrms
  - **VDC:**  $\pm 40, 70$  mA max (Require DC Bias Option B on Alpha-A Mainframe)
  - **Output Impedance:**  $50\ \Omega$
  - **Input Impedance:**  $10^{14}\ \Omega$



## 2.10 MODULAR SOLUTIONS: SAMPLE CELL, TSDC

SAMPLE CELL	FEATURES	GENERAL SPECIFICATION	REMARKS
<p style="text-align: center;"><b>TSDC</b></p> 	<ul style="list-style-type: none"> <li>▪ For measurement of Thermally Stimulated Depolarization Current and Conductivity (TSDC)</li> <li>▪ Integrated Pt100 Temperature sensor near sample</li> <li>▪ Stainless steel construction</li> <li>▪ Gold plated electrodes</li> <li>▪ Two SHV connectors for connection to Electrometers or High Voltage Source</li> <li>▪ Integrated interlock switch for high voltage, enabled if mounted into the temperature environment</li> <li>▪ Easy to use sample mounting spring-loaded mechanism</li> <li>▪ Electrical insulation properties, enable sample current down to 10fA</li> </ul>	<ul style="list-style-type: none"> <li>▪ Frequency <sup>*[1]</sup>: DC to 10MHz</li> <li>▪ Temperature: -200 °C to 250 °C</li> <li>▪ Sample Ø: 40mm max.</li> <li>▪ Sample thickness: 50um to 4mm</li> </ul> <p><b>Require WINTSC Control and Evaluation Software</b></p> <p><b>Applicable Measurements;</b></p> <ul style="list-style-type: none"> <li>▪ Thermally Stimulated Depolarization / Polarization</li> <li>▪ Isothermal Polarization Time domain</li> <li>▪ isothermal Conductivity Time Domain</li> <li>▪ Relaxation Map Isotherm</li> <li>▪ Relaxation Map Thermal window</li> </ul>	<p><b>Supported 3<sup>rd</sup> Party Instruments;</b></p> <ul style="list-style-type: none"> <li>▪ Keysight B2985A Electrometer</li> <li>▪ Keithley 6517A/B Electrometer</li> </ul> <p><b>Supported Temperature Controller;</b></p> <ul style="list-style-type: none"> <li>▪ Quatro Cryosystem: -160 °C to 400 °C</li> <li>▪ Novocool: -100 °C to 250 °C</li> <li>▪ Novotherm: ambient to 400 °C</li> </ul> <p><b>Example processes studied by TSDC Technique</b></p> <ul style="list-style-type: none"> <li>▪ Ageing (Polymers and ceramics)</li> <li>▪ Charge carriers trapping, density and mobility</li> <li>▪ Bulk thermal relaxations</li> <li>▪ Interfacial relaxations</li> <li>▪ Defects</li> </ul>

[1] Dependent on selected frequency option for Alpha-A Mainframe

## 2.11 MODULAR SOLUTIONS: LIQUID SAMPLE CELL, BDS 1307

- The **BDS 1307** liquid sample cell with cylindrical electrodes and guard ring avoids errors related to the thermal expansion of a measured liquid, protects against sample leakage and reduces evaporation. It also increases the accuracy of the measurement by decreasing the influence of fringing fields.
- In contrast to the sealed BDS 1308 parallel plate liquid cell, BDS 1307 has a fixed cell geometry and requires no spacers which simplifies sample preparation.
- The sample liquid is filled in the blue cylindrical volume up to approximately the middle of the guard electrode. The electrical field is confined between the inner and outer electrode and no field exists in the region between the guard and inner electrode. Hence, the cell capacity is nearly independent from the liquid level which may change due to thermal expansion in experiments with temperature variation.
- BDS1307 is mounted in the same way as the standard sandwich capacitor between the electrodes of the **BDS1200 or ZGS active sample cell**.

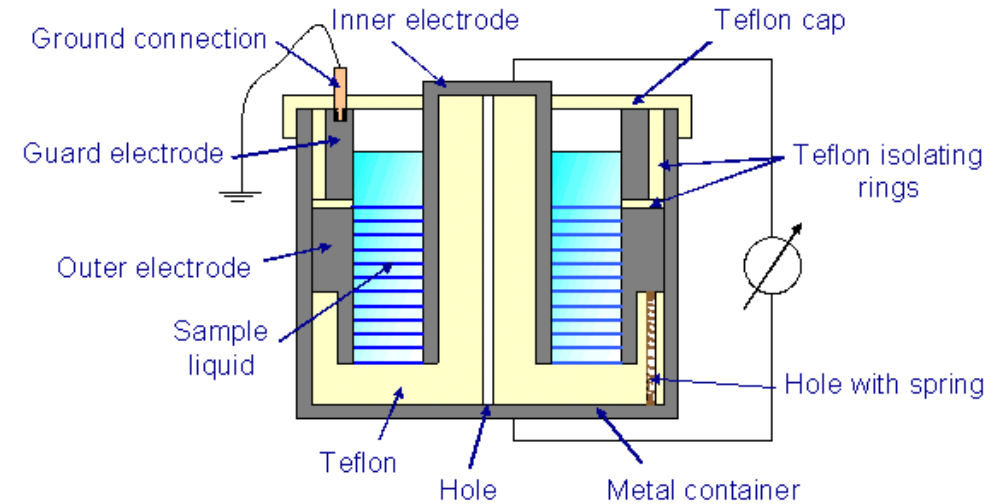


FIGURE 2.9.1: Schematic of the assembled sample cell. The sample liquid is represented by the blue shading and the blue lines show the effective measuring field.



FIGURE 2.9.2: BDS 1307 LIQUID SAMPLE CELL

## 2.12 MODULAR SOLUTIONS: LIQUID SAMPLE CELL, BDS 1308

- For volatile liquids with low partial pressure, sample material may evaporate out of the standard sandwich capacitor and the measurement accuracy may decrease.
- In order to prevent evaporation, the **parallel plate liquid sample cell BDS1308** can be used. In contrast to the BDS 1307 cylindrical liquid cell with guard ring, BDS 1308 is sealed and allow to adjust the cell capacity by variation of the electrode spacing.
- In the **OPEN STATE**, the cell closing plate and upper electrode are removed from the cell, and the sample material covers the lower electrode. The electrodes gap is adjusted by **Silica or Teflon spacers**.
- In the **CLOSED STATE**, the upper electrode is pressed by the cell closing plate and the spring to the spacers.
- Liquid sample material, which does not fit between the electrodes, can flow around the upper electrode. The two seal rings attached to the Teflon isolation prevent evaporation of sample materials out of the cell.
- BDS1308 is mounted in the same way as the standard sandwich capacitor between the electrodes of the **BDS1200 or ZGS active sample cell**.

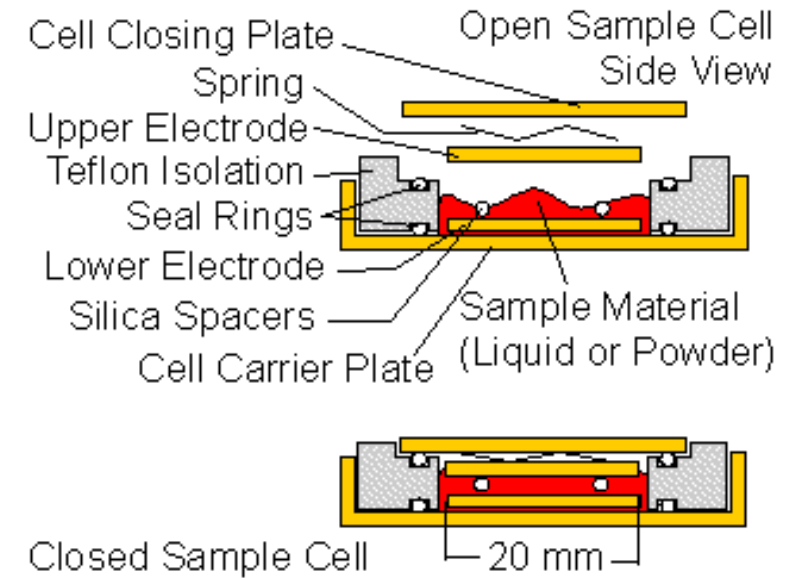


FIGURE 2.10.1: Schematic of LIQUID SAMPLE CELL BDS 1308



FIGURE 2.9.2: BDS 1307 LIQUID SAMPLE CELL

## 2.13 MODULAR SOLUTIONS: RF SAMPLE CELL, BDS 2100 AND BDS 2200

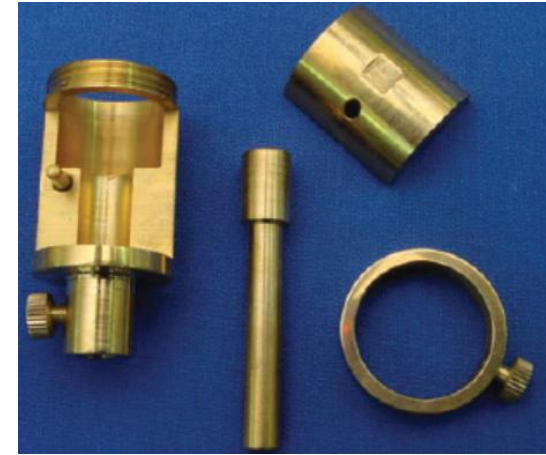
- The **BDS2100** and **BDS2200** RF sample cells are designed for dielectric and impedance material measurements from 1MHz to 3 GHz. They are used in the following Novocontrol Turnkey Systems;

- BDS 70
- Concept 70
- BDS 80
- Concept 80

and as part of the RF extension line.

- For measurements without temperature control, they can be directly connected to a RF impedance or network analyzer APC-7 connector port. For usage with our temperature control systems, the **RF extension line** is required as well.
- Sample is prepared between 2 sandwich electrodes building a sample capacitor similar to the BDS1200 cell.
- The BDS 2100 and BDS2200 have inner diameters of 7mm and 14mm respectively.
- Sample capacitor RF electrodes are available from 3 to 12 mm diameter. Due to the spatial restriction, the maximum electrode diameter for the **BDS 2100 is 6 mm**.
- Electrode spacing may be selected between 10 $\mu$ m and 5mm.
- **BDS 2100** can be used in the frequency range from **1MHz to 8GHz**. RF electrodes from 3mm to 6mm diameter may be used.

**Note:** Electrodes with larger diameters are easier to handle. Hence, BDS 2200 is recommended except if frequency > 3GHz is required.



BDS 2100 (7mm)  
BDS 2200 (14mm)

## 2.14 MODULAR SOLUTIONS: RF SAMPLE CELL, BDS 2214

- **BDS2214** is a RF Liquid Sample Cell with gold plated cup electrode of 12 mm diameter that is ideal for RF measurements of liquids with low viscosity. They are used in the following Novocontrol Turnkey Systems;
  - BDS 70
  - BDS 80
  - Concept 70
  - Concept 80and as part of the RF extension line.
- Small spacers (eg 50um silica fibers) can be used to separate the cup electrode and the top electrode. The top electrode has a diameter of 10 mm so that surplus material is pressed out of the electrode area automatically.



BDS 2214

## 2.15 MODULAR SOLUTIONS: MAGNETIC SAMPLE CELL

- For magnetic materials measurements, the dielectric/impedance RF sample cell is replaced by a magnetic cell and mounted at the end of the RF extension line.
- The RF extension system operates from 1MHz to 3 GHz.
- The sample must adopt the geometry of a cylindrical ring with specific dimensions of the sample cell and placed in the center.
- If the sample cell is completely filled by the sample material, the magnetic permeability  $\mu^*$  of the sample material can be calculated from the complex sample inductivity by eqn [2];

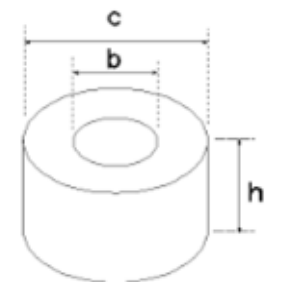
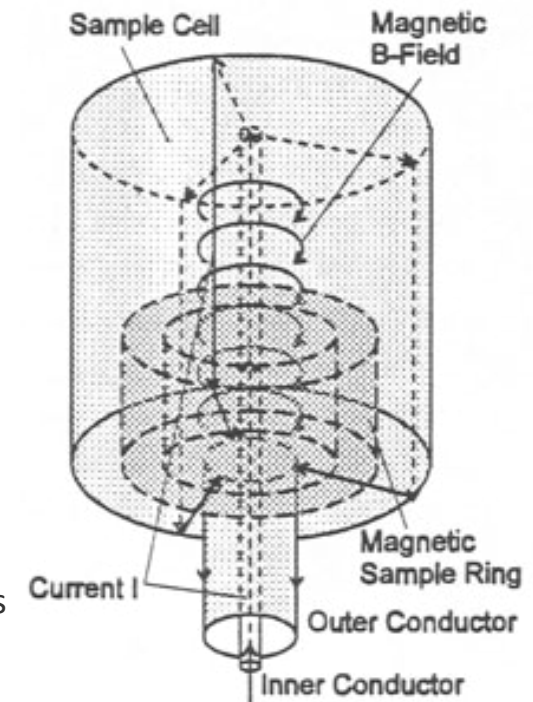
$$\mu^* = \mu' - j\mu'' \quad \text{eqn [1]}$$

$$\mu^* = L^*/L_0 \quad \text{eqn [2]}$$

$$L^* = j\omega Z^* \quad \text{eqn [3]}$$

- In practice, sample material must not completely fill the cell. In this case the inductivity of the not filled cell volume is subtracted from the measurement impedance in eqn [2].
- Magnetic material properties can also be determined under computer control with or without temperature control as these measurements are available as an option on Novocontrol software.

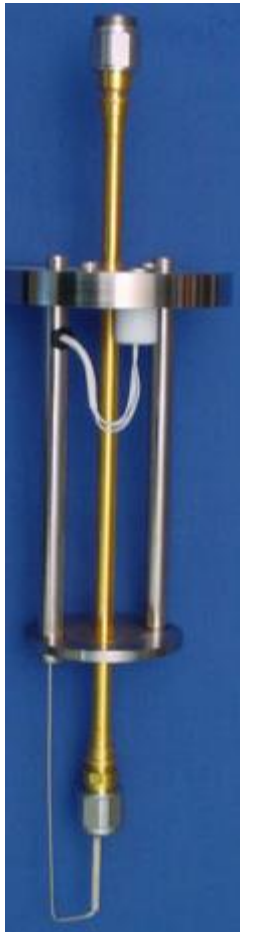
Principle of the sample cell for magnetic material measurements



Example of Magnetic Sample Geometry

## 2.17 MODULAR SOLUTIONS: RF EXTENSION LINE

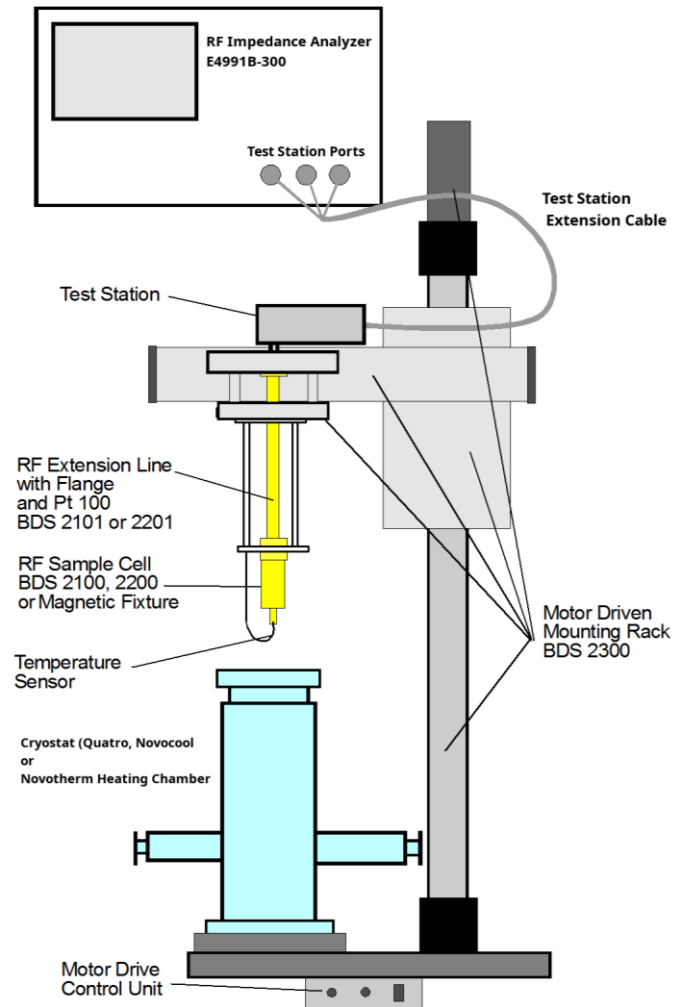
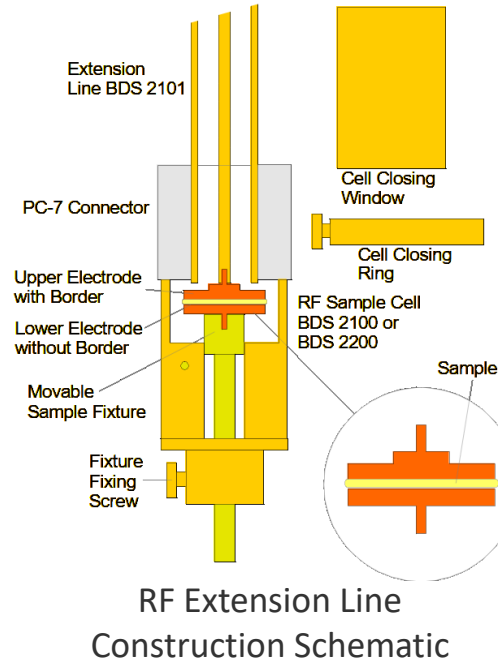
- For temperature dependent RF measurements up to 3 GHz, the **BDS 2101** or **BDS 2201** RF Extension Lines are recommended. This is part of Novocontrol RF Extension System.
- This is a high-temperature stable, low-loss precision line with two APC-7 connectors and Pt100 temperature sensor.
- It is mounted between the impedance input of the RF Analyzer and the RF sample cell for thermal isolation.
- **BDS 2101** includes the RF sample cell **BDS 2100 (inner diameter 7mm)**.
- **BDS 2201** includes sample cell **BDS 2200 (inner diameter 14mm)**.
- The combination of sample cell and extension line can be operated in the temperature range from  $-200\text{ }^{\circ}\text{C}$  to  $400\text{ }^{\circ}\text{C}$  depending on the selected temperature controller.
- RF extension system includes RF sample cell BDS 2200, RF extension line, BDS 2300 mounting rack and an RF impedance analyzer Keysight E4991B-300



RF Extension  
Line

## 2.17 MODULAR SOLUTIONS: RF EXTENSION LINE

- Sample is mounted in parallel plate arrangement between two RF external electrodes which are mounted in the RF sample cell.
- The RF cell is thermally isolated by the RF extension line which connects the RF cell to the impedance port of the RF analyzer.
- As this setup is very sensitive to mechanical stress, it is supported by the motor driven **BDS 2300 mounting rack** which allows to move the sample cell in and out of the cryostat by special mechanics avoiding mechanical forces on the extension line and APC-7 port connections.



## 2.18 MODULAR SOLUTIONS: INTERDIGITATED ELECTRODES

- Interdigit electrodes may be used in combination with the BDS1200- or ZGS Alpha active sample connection head for temperature dependent measurements or direct connected to the impedance analyzer.
- Sample material covers the surface of a comb micro structure electrode.
- Compared to the parallel plate electrodes, interdigit electrodes are less accurate but easier to handle.
- Interdigit electrodes may be used at temperatures from  $-160^{\circ}\text{C}$  to  $+250^{\circ}\text{C}$ .
- **Advantages:**
  - Sample attached only at one side of the electrode, leaving the other side of the sample free for other probes (e.g., optical) to simultaneously observe other materials properties. In addition, sensor applications may probe the electrical properties of samples under the influence of electromagnetic radiation or gases.
  - In typical applications, sample thickness does not influence the measured properties.
- **Drawbacks:**
  - Measured impedance contains contributions from both sample and interdigit electrode substrate. This might lead to significant errors, especially for low loss/highly insulating samples
  - For highly conducting samples measured at high frequencies, the resistance and inductance of the interdigit electrodes represents a significant part of the overall measured impedance. Since this effect is difficult to compensate, the use of interdigit electrodes has a limited frequency and impedance range.

## 2.18 MODULAR SOLUTIONS: INTERDIGITATED ELECTRODES

- **Comb Micro Structure Electrode Geometry;**
  - Diameter available: 20mm and 15mm
  - Spacing between the comb fingers and their widths: 75 $\mu$ m and 150 $\mu$ m
- **High-Quality Version: BDS 1410**
  - To order, specify BDS 1410 - <diameter/mm> - <spacing/ $\mu$ m>, e.g., BDS 1410-15-75 for 15 mm diameter and 75  $\mu$ m spacing. Currently available:
    - BDS 1410-15-75
    - BDS 1410-15-150
    - BDS 1410-20-150
- **Low-Cost Version: BDS 1411**
  - To order, specify BDS 1411 - <diameter/mm> - <spacing/ $\mu$ m>, e.g., BDS 1410-15-75 for 15 mm diameter and 75  $\mu$ m spacing. Currently available:
    - BDS 1411-15-75
    - BDS 1410-2!-150
- Other dimensions upon request.

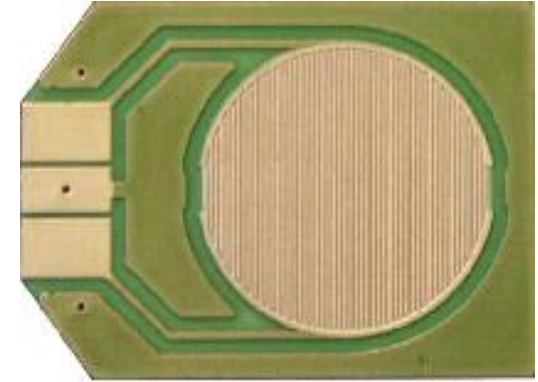


FIGURE 2.11.1: BDS 1410

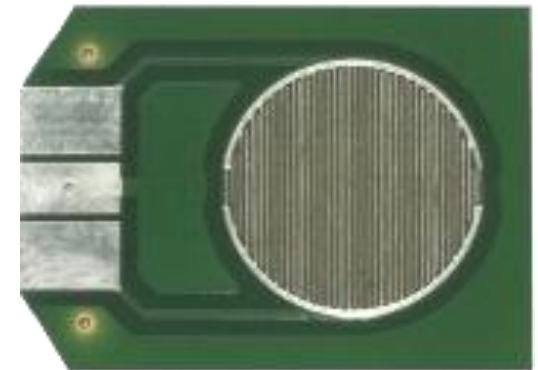


FIGURE 2.11.2: BDS 1411

## 2.19 MODULAR SOLUTIONS: TEMPERATURE CONTROLLER, NOVOTHERM

- Economical turnkey modular temperature control system, designed for easy, safe and fully automatic operation for applications in material characterization.
- System sets or ramps the temperature of the sample under test. Can be combined with Novocontrol sample cells and dielectric or impedance spectrometer for dielectric and impedance spectroscopy.
- Temperature: Ambient to 400°C
- Temperature Ramp: 0.01 to 20°C/min
- Temperature Accuracy and Stability: 0.1°C
- Temperature Overshoot: Typical <1°C after setpoint
- Stabilization Times: Typical < 5 minutes (for 0.1 °C stability)
- Communication Port: GPIB



## 2.20 MODULAR SOLUTIONS: TEMPERATURE CONTROLLER, NOVOCOOL

- The Novocool Cryosystem is an economical turn key temperature control system, designed for easy, safe and fully automatic operation for applications in material characterizations.
- It can be used with all Novocontrol sample cells for dielectric and impedance spectroscopy.
- The system sets or ramps the temperature of the sample under test with fast stabilization with tuned controlled parameters.
- Temperature: -100°C to 200°C
- Temperature Ramp: 0.1 to 20°C/min
- Temperature Accuracy: 0.3°C
- Low liquid nitrogen consumption: <1.5 l/hr at T> -50 °C
- Communication Port: GPIB
- Dimension (approximate):

PART	WIDTH (cm)	HEIGHT (cm)	DEPTH (cm)
LAB TROLLEY	58	150	62
DEWAR	65	155	65



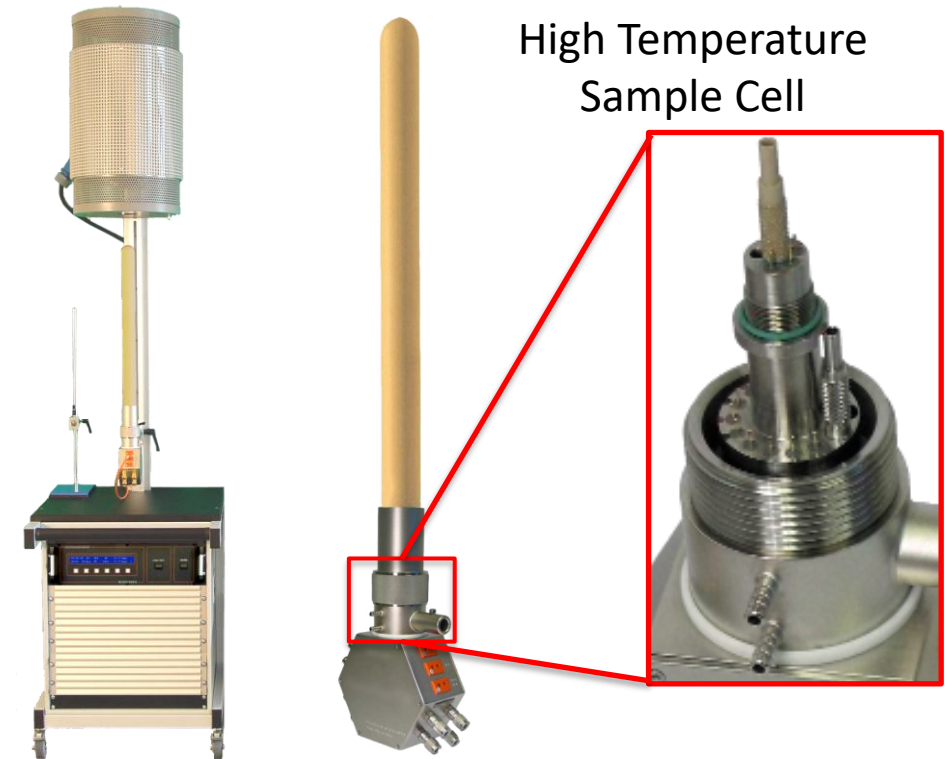
## 2.21 MODULAR SOLUTIONS: TEMPERATURE CONTROLLER, QUATRO CRYOSYSTEM

- Quatro Cryosystem is a high quality turn key temperature control system developed to set or ramp the temperature of the sample under test with high accuracy and reproducibility.
- Can be used with all Novocontrol sample cells for dielectric and impedance spectroscopy.
- Main parts of Quatro Cryosystem consists of;
  - Cryostat BDS 1100
  - Pressurizer module BDS 1320
  - Liquid nitrogen dewar
  - Power supply BDS 1340.
  - Gas Heating Module BDS 1310
  - Vacuum System with BDS 1350
  - Quatro controller BDS 1330
- Temperature: -160°C to 400°C
- Temperature Ramp: 0.01 to 20°C/min
- Temperature Stability: < 8 minutes at 0.1°C stability
- Low liquid nitrogen consumption: <1 l/hr at T> -100 °C
- Purge gas option allow temperature control operation from ambient to 400°C
- The Quatro controller has four circuits controlling the sample temperature; gas temperature, temperature of the liquid nitrogen in the dewar and pressure in the dewar. Additionally, the vacuum pressure is measured. If sensors would fail or the liquid nitrogen dewar becomes empty, the system will automatically shut down.



## 2.22 MODULAR SOLUTIONS: TEMPERATURE CONTROLLER, NOVOTHERM-HT

- **Novotherm-HT** was designed for easy, safe and fully automatic operation up to 1600 °C including a sample cell for dielectric, conductivity and impedance measurements under controlled atmosphere or vacuum (e.g. vacuum, inert gas, reactive gas, pH<sub>2</sub>O, etc).
- Frequency range covered by the sample cell is DC to 1MHz and can be operated with all Novocontrol Analyzers and test interfaces **except ZGS and G22**.
- Available Systems:
  - Novotherm-HT 1200: Ambient to 1200°C
  - Novotherm-HT 1400: Ambient to 1400°C
  - Novotherm-HT 1600: Ambient to 1600°C
- Application examples include;
  - Fuel Cell Components Test
  - Electrode kinetics
  - Sensor Test
  - Determination of the ionic transport numbers of membranes
  - Permittivity and conductivity measurements vs T, pH<sub>2</sub>O, etc
  - Determination of the ionic transport numbers of membranes
  - Electrochemical pumping, gas permeation and electrocatalysis with gas analysis (e.g. GC or MS) on outlets

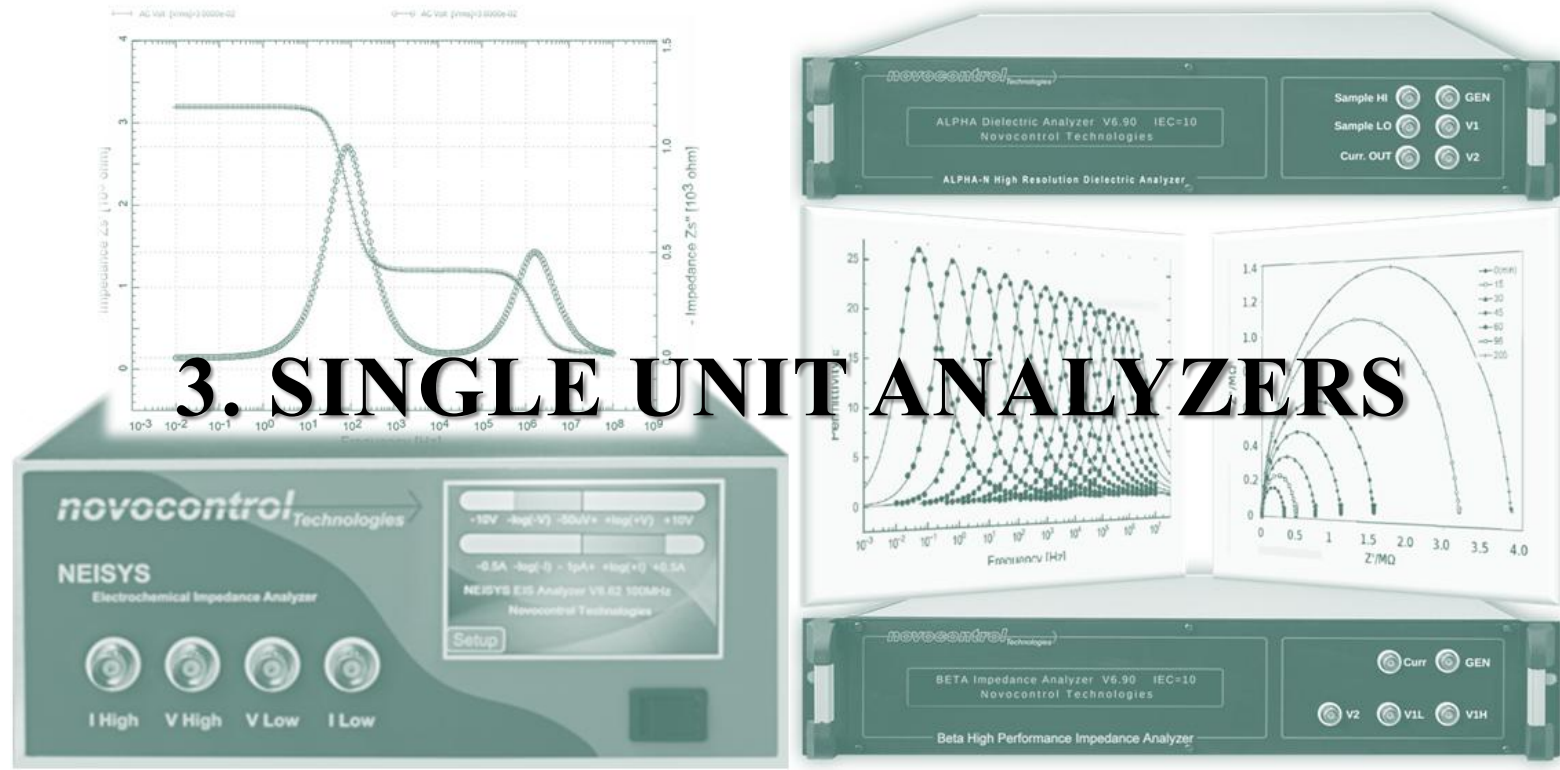


## 2.23 MODULAR SOLUTIONS: TEMPERATURE CONTROLLER, PHECOS

- **PHECOS** is a *Peltier-based Heat/Cool System* based on a dual-stage Peltier element whose sole resource is electrical power, no cryogenic fluids are required for the temperature control operation. Fully automatic operation for applications in material characterizations that include Dielectric, Conductivity and Electrochemical Impedance (EIS) spectroscopy. Compatible with Novocontrol Dielectric / Impedance analyzers, potentiostats / galvanostats and high voltage interfaces.
- Supports external gas inlets and outlets for defined atmosphere within the sample cell volume.
- Modular setup with several sample cell set-ups (for e.g. dielectric and impedance material measurements, 2, 3 or 4 wire configurations for electrochemical samples) and interdigit electrodes (for e.g. monitoring of chemical reactions and curing of epoxies or glues or paints).
- Available Systems:
  - PHECOS: -50°C to 200°C (for  $T_{\text{ambient}} < 25^{\circ}\text{C}$ ) <sup>\*[1]</sup>
  - PHECOS LITE: -35°C to 150°C (for  $T_{\text{ambient}} < 25^{\circ}\text{C}$ ) <sup>\*[1]</sup>
- Temperature Stability and Accuracy: 0.1°C / 0.2°C
- Temperature Ramp: 0.01°C/min up to 30°C/min
- Stabilization Time: Typical <5 minutes (for 0.1 °C stability)



[1] Exact limits will depend on the particular sample fixture used (eg standard fixture for dielectric samples (PHECOS-BDS) will change the operating temperature range to -45 °C to 190 °C



### 3. SINGLE UNIT ANALYZERS

## NEISYS, ALPHA, BETA

## 3.1 SINGLE UNIT ANALYZER: NEISYS

- **NEISYS** is a compact high-performance analyzer for electrochemical impedance measurements combining potentiostatic and galvanostatic functions with a state-of-the-art electrochemical impedance analysis system in a compact case with small footprint. A versatile analyzer well suited for many standard Electrochemical Impedance Spectroscopy (EIS) applications.
- Standard configuration can be extended by various options wherever needed. Examples are high-measurement rates and higher frequency options, extended ranges and accuracy, and particular applications like non-linear spectroscopy/higher harmonics analysis.
- An easy-to-use software (running on contemporary Windows systems) with Ethernet system interface.
- Sample Connection (BNC): 2, 3, 4-wire (I High, V High, V Low, I Low)
- Main Control Loop Operation Modes: Potentiostat, Galvanostat and Direct Voltage
- Voltage / Current Measurement (in Time domain): **10V / 500mA**
- Impedance Range\*: **1E10<sup>-4</sup> Ω to 1E10<sup>12</sup> Ω**
- Capacitance Range\*: **1E10<sup>-15</sup>F to 1E10<sup>3</sup>F**
- Inductance Range\*: **1E10<sup>-7</sup>H to 1E10<sup>3</sup>H**



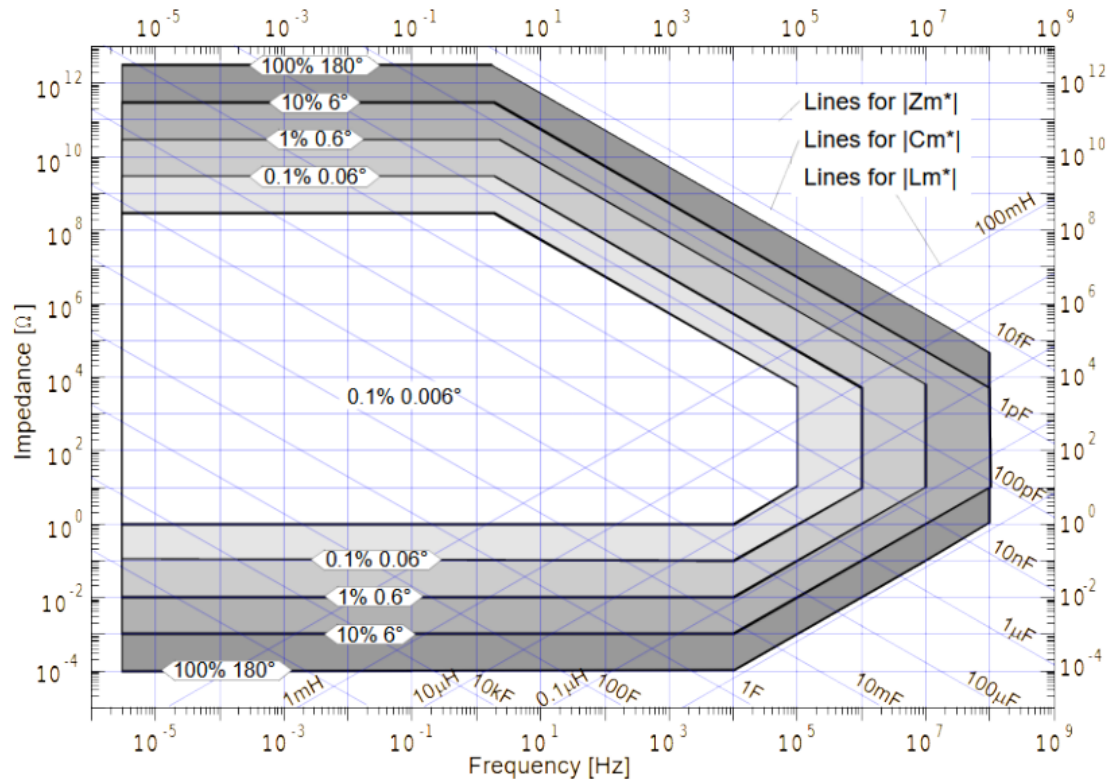
\* **NOTE:** For details of measurement range and accuracy, refer to Impedance Measurement charts

## 3.1 SINGLE UNIT ANALYZER: NEISYS

- **Counter Electrode Polarization High**
  - Voltage / Current:  $\pm 10\text{Vp}$  /  $500\text{mA}$  DC and, or AC
  - Potentiostat Mode: Same as  $V_{\text{high}}$ ,  $V_{\text{low}}$  inputs
- **Working Electrode Current Input I Low**
  - Current Range:  $5\text{nA}$  to  $500\text{mA}$
  - Bandwidth: DC to  $100\text{MHz}$
- **Frequency range Options;**
  - **NEISYS 1M:**  $3\text{mHz}$  to  $1\text{MHz}$
  - **NEISYS 50M:**  $3\text{mHz}$  to  $50\text{MHz}$
  - **NEISYS 10M:**  $3\text{mHz}$  to  $10\text{MHz}$
  - **NEISYS:**  $3\text{mHz}$  to  $100\text{MHz}$
- **Sample Rate Options;**
  - **NEISYS 1MPts:** Sample rate extension up to  $10^6$  voltage/current data points/second
  - **NEISYS 10MPts:** Sample rate extension up to  $10^7$  voltage/current data points/second
- **High Accuracy and Extended Functionality Options;**
  - **NEISYS HAC:**  $0.1\%$  (time domain),  $0.03\%$  (frequency domain)
  - **NEISYS EXF (Extended Functionality):** User-defined arbitrary waveforms, Adjustable current and voltage limits, Sampling times adjustable in individual ramp intervals, Higher harmonics, Non-linear spectroscopy, Fast measurement (up to  $500$  impedance points per second), Low-frequency limit:  $3\ \mu\text{Hz}$ , Advanced Mode Extension for NEISYS DETACHEM software

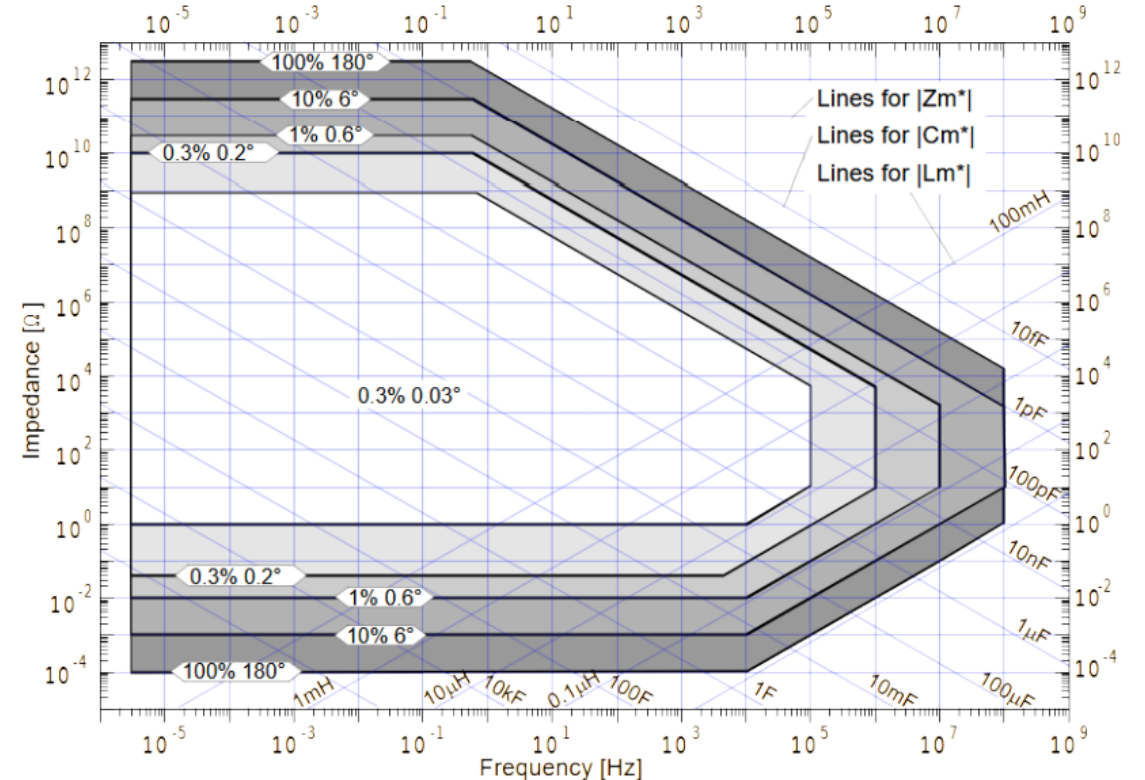
# 3.1 SINGLE UNIT ANALYZER: NEISYS

## ■ IMPEDANCE MEASUREMENT CHART



NEISYS impedance measurement accuracy with option HAC (high accuracy)

**AC Sample Voltage:  $\pm(0.03V \text{ to } 7)V_{rms}$**



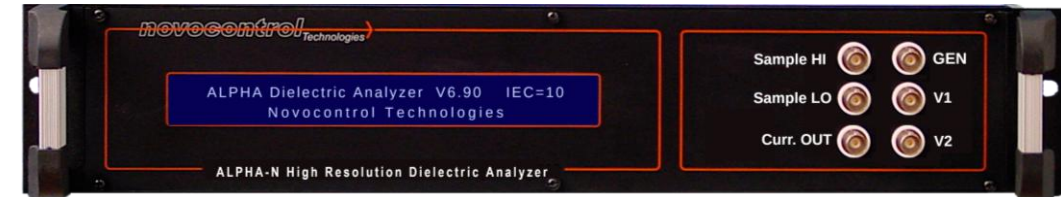
NEISYS impedance measurement accuracy without option HAC (high accuracy).

**AC Sample Voltage:  $\pm(0.01V \text{ to } 7)V_{rms}$**

- Specification applicable for Direct Voltage or Potentiostat modes, 100us Time Constant, No DC voltage or current, Auto-Ranging Impedance, 0.5s Measurement Time, Sample connected to front panel BNC Terminals

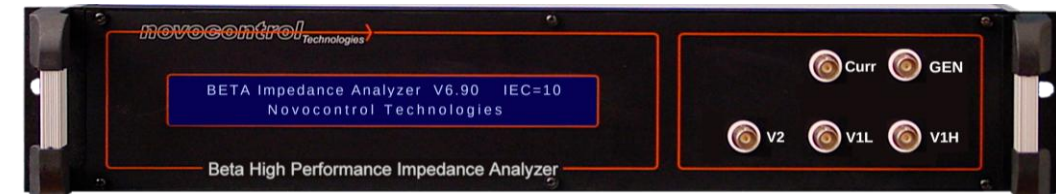
## 3.2 SINGLE UNIT ANALYZERS: ALPHA

- **ALPHA** analyzer features 2 electrodes for Dielectric, Conductivity, Impedance Spectroscopy and Gain Phase measurements.
- Frequency Range:  $3\text{E}10^{-5}\text{Hz}$  to  $4\text{E}10^7\text{Hz}$  (Dependent on option) including low frequencies for characterization of dielectric relaxations, electrochemical and high impedance effects;
  - **Alpha-L:** 3uHz to 300kHz
  - **Alpha-N:** 3uHz to 20MHz
  - **Alpha-K:** 3uHz to 3MHz
  - **Alpha-T:** 3uHz to 40MHz
- Impedance Range:  $1\text{E}10^{-2}\Omega$  to  $1\text{E}10^{14}\Omega$
- Capacitance Range:  $1\text{E}10^{-15}\text{F}$  to 1F
- Differential Voltage Input Impedance:  $1\text{E}10^{12}\Omega$  | 10 pF
- Phase and loss factor  $\tan(\delta)$  absolute accuracy:  $0.002^\circ$  and  $3\text{E}10^{-5}$  respectively
- DC Bias **Option B:**  $\pm 40\text{V}$ , 70mA
- Self calibration to cancel out long term internal drift and user diagnosis to verify functionality
- **DETACHEM** Control and Data Evaluation Software



## 3.3 SINGLE UNIT ANALYZERS: BETA

- **BETA analyzer** has the same functionality of ALPHA analyzer, but additionally supports 3 and 4 electrode configurations that can be of advantage used to partly compensate electrode; sample interface polarization or contact impedance effects.
- Frequency Range:  $3\text{E}10^{-5}\text{Hz}$  to  $4\text{E}10^7\text{Hz}$  (Dependent on option) including low frequencies for characterization of dielectric relaxations, electrochemical and high impedance effects;
  - **Beta-L:** 3uHz to 300kHz
  - **Beta-N:** 3uHz to 20MHz
  - **Beta-K:** 3uHz to 3MHz
  - **Beta-T:** 3uHz to 40MHz
- Impedance Range:  $1\text{E}10^{-2}\Omega$  to  $1\text{E}10^{14}\Omega$
- Capacitance Range:  $1\text{E}10^{-15}\text{F}$  to 1F
- Differential Voltage Input Impedance:  $1\text{E}10^{12}\Omega$  | 10 pF
- Phase and loss factor  $\tan(\delta)$  absolute accuracy:  $0.002^\circ$  and  $3\text{E}10^{-5}$  respectively
- DC Bias **Option B:**  $\pm 40\text{V}$ , 70mA
- Self calibration to cancel out long term internal drift and user diagnosis to verify functionality
- **DETACHEM** Control and Data Evaluation Software



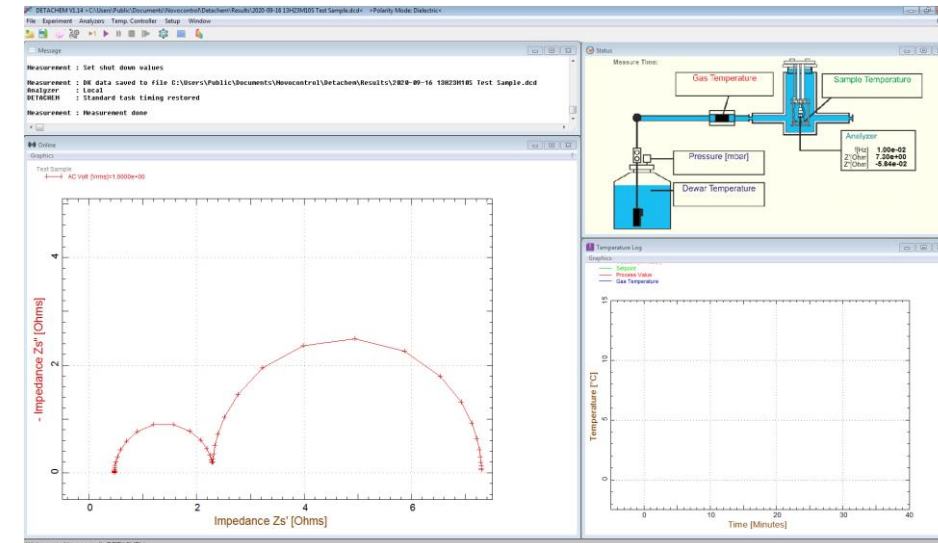


## 4. SOFTWARE

**CONTROL, EVALUATION, ANALYSIS**

# 4.1 SOFTWARE: DETACHEM

- Control and evaluation software offers three different types of measurement;
  - **Frequency Domain:** For Dielectric and Electrochemical Impedance Spectroscopy
  - **Time Domain:** For all voltage/current measurements with predefined waveforms of voltage or current (potentiostatic and galvanostatic modes, respectively)
  - **Gain Phase:** For Gain-Phase measurements. Use of an ac signal and detect two complex voltage signals probed at two different parts of a device under test
- Automatic detection of supported impedance analyzers and temperature control systems
- Performs calibration automatically with step-by-step procedures for the sample cells
- Allows dielectric and impedance measurements up to four dimensions as a function of frequency, temperature, time, AC voltage or AC bias or any multi-dimensional combination
- Basic dielectric and impedance parameters, like complex dielectric function, modulus, conductivity, impedance etc., are evaluated and displayed graphically in two- or three-dimensional representation.

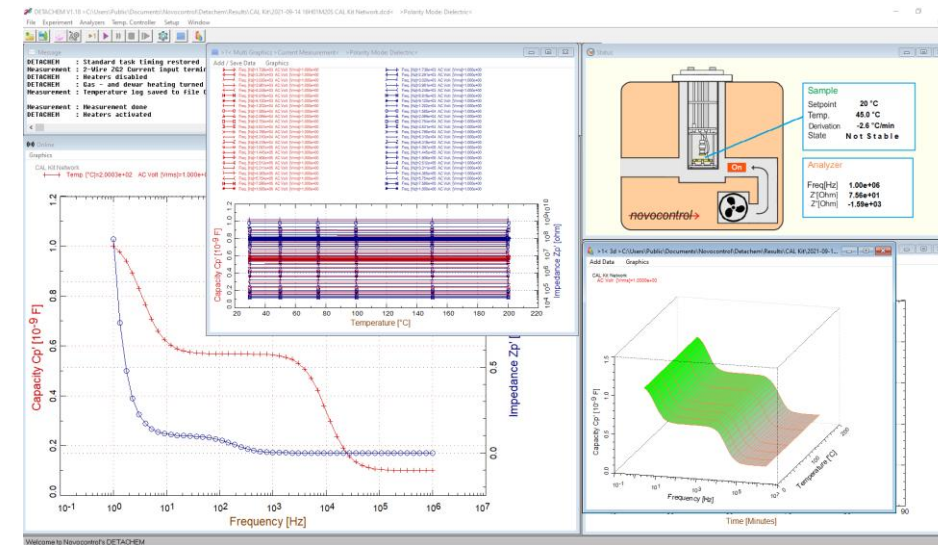


# 4.1 SOFTWARE: DETACHEM

- **Supported OS:** Windows 11, 10, 8, 7, both 64- and 32- bit versions
- User define/save/load experiment setups
- Measurement Option: Single Sweep, Start, Stop, Pause, Resume
- Multigraphics / 3D data View Display
- Auto-update of data display during measurement
- Export and import data in several flexible ASCII formats (spreadsheet, txt)
- Predefined plots for faster access to preferred data representations
- Loading of measurement result files during measurement with additional Multigraphics windows

## DETACHEM OPTIONS:

- **TEMP Option:** Support of temperature-controlled measurements with drivers for all Novocontrol temperature control systems and industrial controllers. Includes isothermal experiments from temperature lists and / or temperature lists with ramps. By combination several isothermal temperatures and several ramps, any arbitrary temperature time dependence can be programmed.
- **DETACHEM-All Option:** Includes drivers for three different impedance analyzers instead of one.



## 4.2 SOFTWARE: WINFIT

- WinFIT is curve fitting analysis software for non-linear models analysis of dielectric and impedance spectra.
- Advanced curve fitting techniques are used to ensure accurate and fast determination of material parameters.
- Equivalent Circuit Analysis for impedance spectra is extended by arbitrary complex functions.
- Special evaluations for dielectric measurements in polymer research are included like Havriliak Negami functions, Williams Landel Ferry (WLF), master plots and time domain conversion.
- **Frequency Domain**
  - Non linear curve fitting in the frequency domain
  - Special fit functions like Havriliak Negami, Cole Cole, Cole Davidson, Debye etc.
  - Automatically evaluates a series of spectra for several temperatures
  - Separates relaxation from conductivity contributions
  - Automatically creates master plot representations
- **Time Domain**
  - Converts dielectric data by numerical Fourier Transform from frequency to time domain
  - Supports complete dielectric time domain representation including relaxation time distribution, relaxation function, step response function, peak answer function, time dependent dielectric constant and conductivity

# 4.2 SOFTWARE: WINFIT

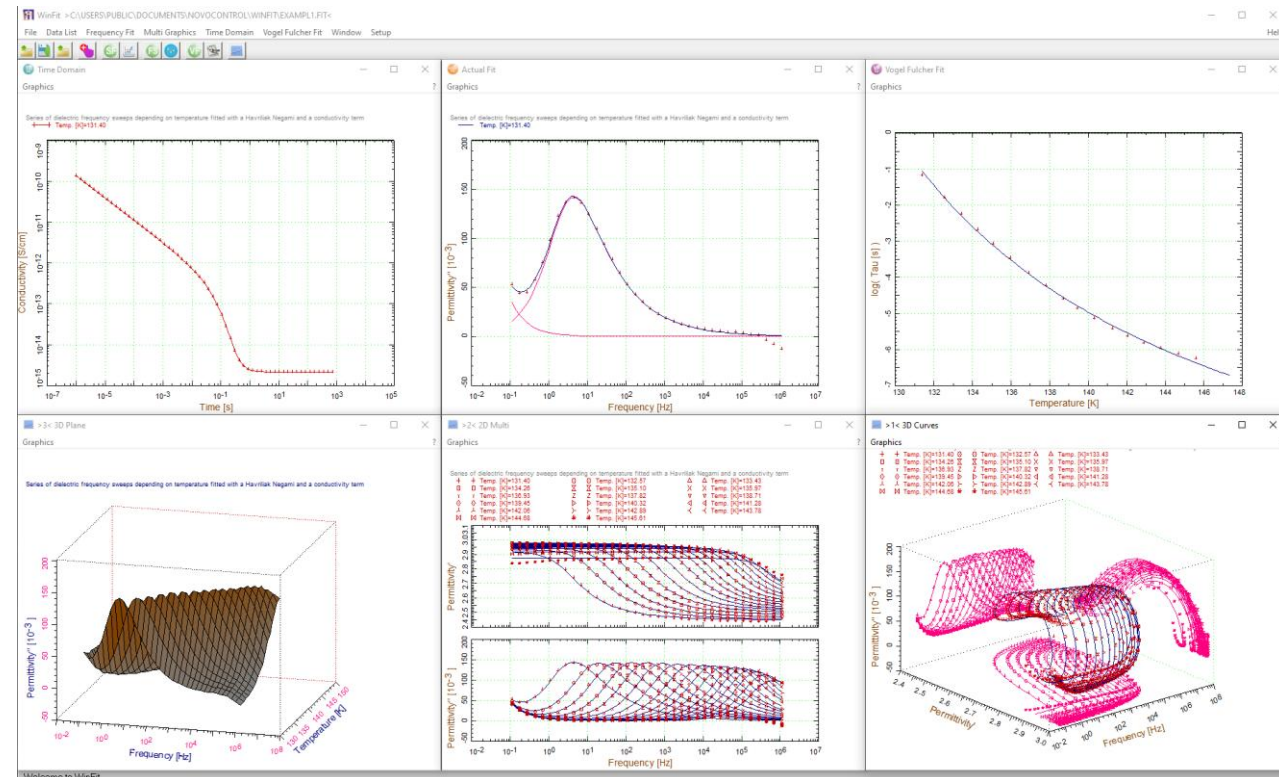
## Temperature Domain

- Non linear curve fitting in the temperature domain including Vogel - Fulcher and Williams Landel Ferry (WLF) fit functions
- Fits relaxation time and maximum relaxation frequency
- Creates an Arrhenius activation plot related to activation energy and glass temperature

## Data connection and correction

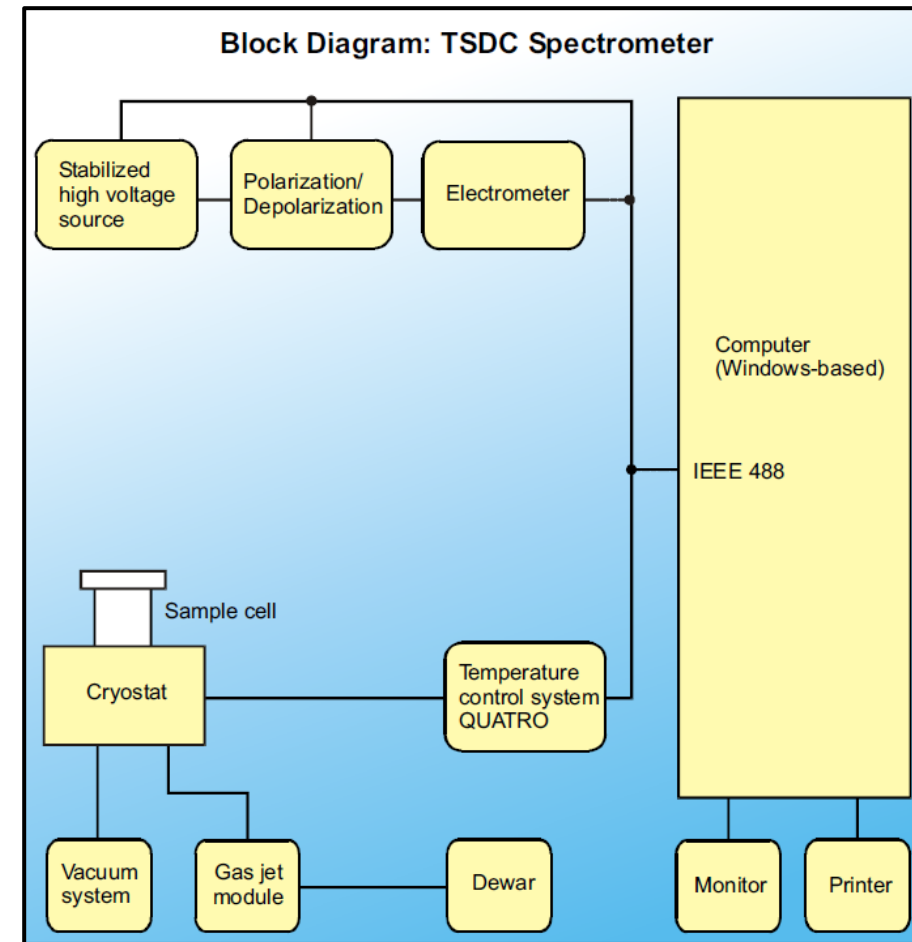
- Shifts, deletes and inserts data points with a single mouse click
- Connects data curves being measured in different frequency ranges with different analyzers

- **Supported OS:** Windows 11, 10, 8, 7, both 64- and 32- bit versions



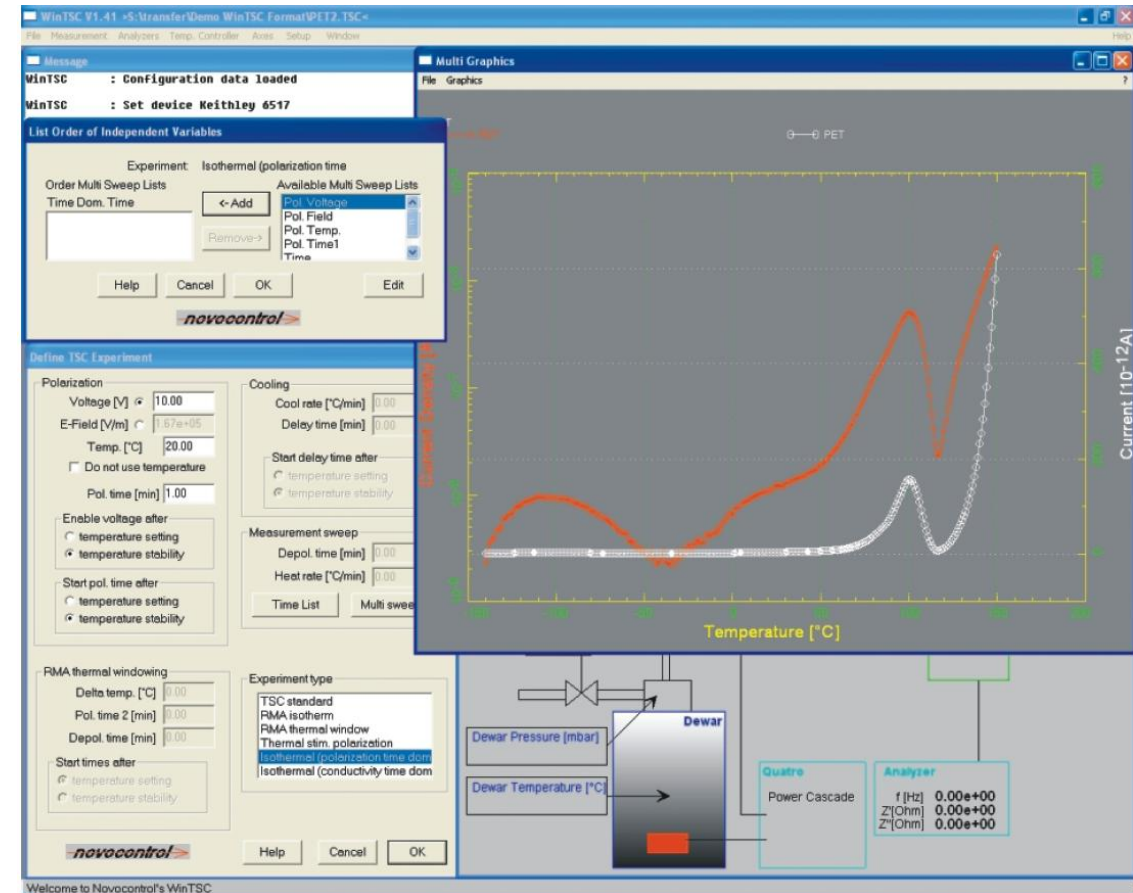
## 4.3 SOFTWARE: WINTSC

- **WinTSC** is the standard control and evaluation software for TSDC system that performs TSDC and time domain measurements as a function of up to four variant parameters (eg temperature, time, polarization voltage, polarization time)
- The polarization current, current density, corresponding charge and delta permittivity are evaluated and displayed in 2- and 3-dimensional online diagrams. Equivalent Circuit Analysis for impedance spectra is extended by arbitrary complex functions
- Evaluates electric quantities (e.g. polarization current density, delta permittivity, conductivity)
- Supports various temperature controllers
- **System Requirement:**
  - Supported OS: Windows 11, 10, 8, 7, both 64- and 32- bit versions
  - Sample Cell TSDC
  - Electrometer (eg Keysight B2985A, Keithley 6517B)
  - High Voltage Source (Novocontrol HVB series)
  - Novocontrol temperature control system (Quatro Cryosystem, Novocool, Novotherm)



## 4.3 SOFTWARE: WINTSC

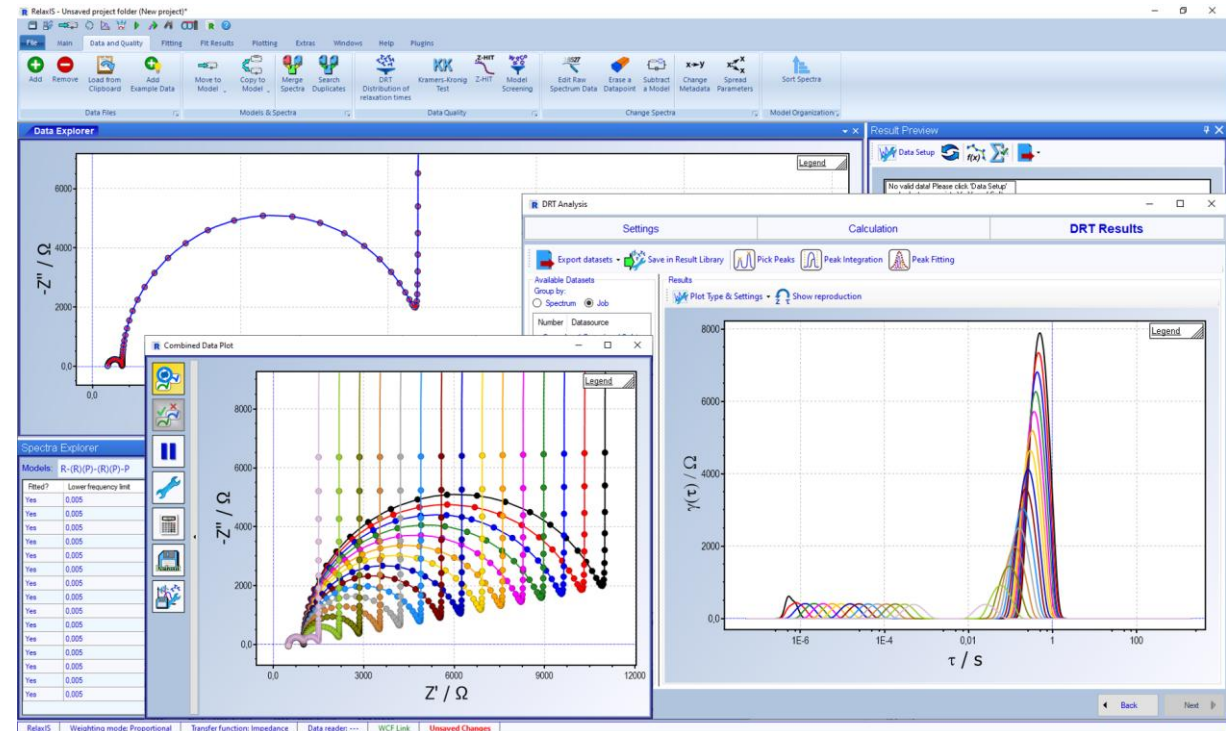
- Control and evaluate multitasking software for TSDC and time domain U-I measurements
- Flexible experiment set-up; temperature control, time, polarization voltage, polarization time and others
- Export/Import data in several flexible ASCII formats
- **Optional Thermal Windowing;**
  - Main function is the evaluation of relaxation maps from a thermal windowing experiment
  - Supports data manipulation functions (eg shifting, deleting of data points, confining and smoothing of data curves)
  - Sample polarization is calculated by numerical integration from the measured depolarization current. Supports several procedures for integration and base line corrections. After conversion of the polarization and depolarization current into the relaxation time, the common relaxation maps are created and shows the single Debye relaxation modes in several representations (eg Arrhenius or a free energy diagram)
  - Supports curve fitting model functions (eg Arrhenius, Vogel Fulcher and Williams Landel Ferry [WLF]) for the relaxation time data



Novocontrol WINTSC

# 4.4 SOFTWARE: RelaxIS

- **RelaxIS** is a data analysis software for **Electrochemical Impedance Spectroscopy (EIS)**
- A great advantage is the ability to read data formats of varying measuring devices as well as the elegant and fast evaluation of numerous series of measurements with many spectra.
- **Application examples:**
  - Investigation of the differential double layer capacity in systems with ionic liquids
  - Temperature-dependent conductivity measurements
  - Investigation of battery components
  - Impedance spectroscopy of dye solar cells
- **OS:** Windows 10/11 with .NET Framework 4.7.2
- **Licensing:**
  - **Floating License:** Installation possible on multiple machines. Simultaneous usage; one machine per license.
  - **License Option:** Permanent or Time-Limited
  - **License Activation:** Offline (USB dongle) or Online



## 4.4 SOFTWARE: RelaxIS

- Robust customizable fitting algorithms
- Autofit-function for quickly fitting arbitrary models without parameter initialization
- Parameter-initialization from shapes (i.e. semicircles) drawn into a spectrum
- Monte-Carlo based estimation of fit parameter uncertainties
- Parameter influence tester showing the impact of each parameter on the fit
- Import of arbitrary, column-based text files using an easy-to-use wizard
- Ability to show multiple different plots (i.e. Nyquist and Bode) at the same time.
- Live-analysis views that automatically show, i.e., DRT or Kramers-Kronig tests while browsing spectra
- Simple derivation of initial values using the intuitive circle- or line-tool, or a genetic algorithm
- Side-to-side comparison (overlay) of multiple spectra
- Ability to use dielectric spectra, given in, e.g., permittivity and with unknown cell geometry
- Within one project, spectra can be assigned to various, arbitrary equivalent circuits
- Circuit-Screening tool supporting the selection of suitable equivalent circuits
- Visualization of data and fit results in impedance, admittance or capacitance representations in Nyquist or Bode plots (customizable)

# 4.4 SOFTWARE: RelaxIS

- Native support of numerous impedance data formats
- Arbitrary number of spectra per project
- Storage of metadata for each spectrum
- Editing of the raw impedance data
- Template-based graph style customization
- 3D-Plot overlay of multiple spectra
- Extensive library of pre-defined equivalent circuits
- Live preview of changes in the fit parameters
- Test Fit function to preview the fit results
- Batch fitting of several related spectra
- DRT (Distribution of Relaxation Times) Analysis
- Linear Kramers-Kronig Test
- Fit wizard for automated evaluation of particular types of spectra (e.g. conductivity measurements)
- Multi-spectrum fits, i.e., "global parameters" or with parameters estimated from metadata-based models.
- Built-in Mott-Schottky analysis of a series of spectra



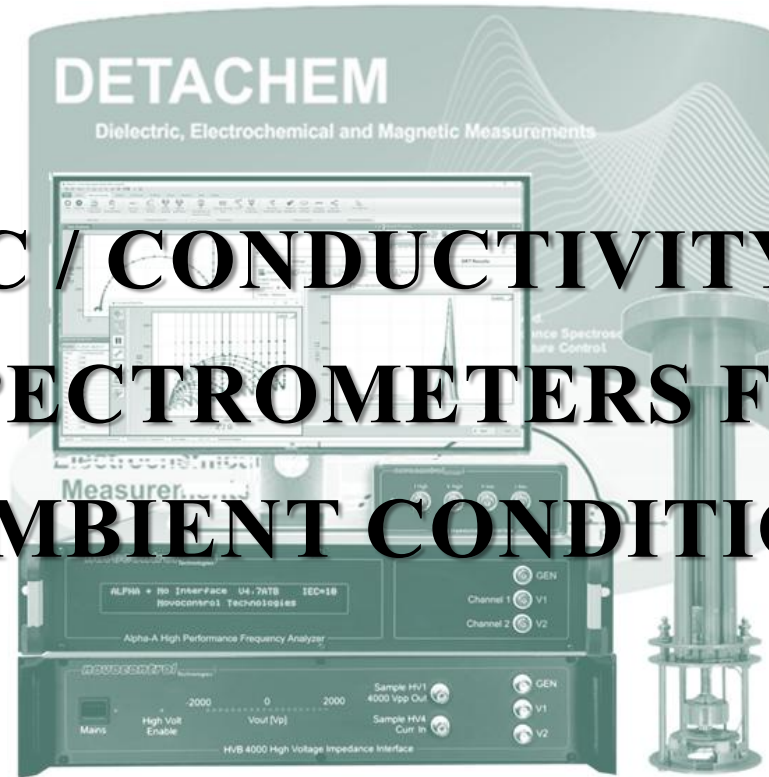
## 4.4 SOFTWARE: RelaxIS

- Result Preview and Evaluation feature that allows the plotting and evaluation of the fit parameters as a function of metadata
  - This implements Arrhenius- and VFT-Fits
  - Includes various other models
- RelaxIS Remote feature for autonomous evaluation and storage of impedance data
- RelaxIS SDK that allows the enhancement of the basic features with plugins
  - Plugins are for example new file formats or circuit elements (and much more)
  - Integrated Code Editor to help with the development of plugins
- RelaxIS WCF Link feature for calling RelaxIS functions (i.e. fitting) from external software on the same PC
- Z-Hit calculation
- Residual analysis and visualization

## 4.4 SOFTWARE: RelaxIS

- Circuit simulator for application in research and teaching
  - Define multiple models with separate, customizable parameter values
  - Freely change the simulated frequency range and number of datapoints
  - Customizable overlay plot of all simulated models
  - Ability to add normal-distributed noise to the data
  - Export-to-RelaxIS function to send simulated spectra to RelaxIS as data
- Extensive export functions for every data type
  - Fit results
  - Impedance spectra with fits
  - Simulated spectra
  - Graphs as images
  - Images of Equivalent Circuits
- Reporting feature that allows the creation of rich, HTML-based summary of fit results

# 5. DIELECTRIC / CONDUCTIVITY / IMPEDANCE SPECTROMETERS FOR AMBIENT CONDITION



## BDS TURNKEY SOLUTIONS

## 5.1 BDS TURNKEY SOLUTIONS: STANDARD

### ▪ **BDS 40 and BDS 50**



- High end systems for the frequency range from 3  $\mu$ Hz to 20 MHz (BDS 40) or 3  $\mu$ Hz to 40MHz (BDS 50)
- Based on the Alpha-A modular measurement system for Dielectric, Conductivity, Electrochemical and Impedance spectroscopy
- Sample impedance is determined by phase-sensitive measurement of sample voltage and current at fixed frequency

### ▪ **BDS 10 and BDS 20**

- Economical versions of BDS 40
- Instead of an Alpha-ANB, the systems are based on an Alpha-NB or Alpha-LB single-unit analyzer
- All other specifications correspond to BDS 40, but apply at the Alpha BNC plugs instead at the sample
- There is no sample cell included. The BDS 1200 cell with shielding unit is recommended and has to be ordered separately

**NOTE: System comes with desktop computer complete with single license DETACHEM software installed  
For Temperature Test, refer to Concept Turnkey Solutions for suitable Temperature Control System**

## 5.1 BDS TURNKEY SOLUTIONS: STANDARD

PARAMETER	BDS 10	BDS 20	BDS 40	BDS 50
				
FREQUENCY (Hz)	$3E10^{-5} \sim 3E10^5$	$3E10^{-5} \sim 2E10^7$	$3E10^{-5} \sim 2E10^7$	$3E10^{-5} \sim 4E10^7$
CAPACITANCE (F)	$1E10^{-15} \sim 1$	$1E10^{-15} \sim 1$	$1E10^{-15} \sim 1$	$1E10^{-15} \sim 1$
IMPEDANCE ( $\Omega$ )	$1E10^{-2} \sim 1E10^{14}$	$1E10^{-2} \sim 1E10^{14}$	$1E10^{-2} \sim 1E10^{14}$	$1E10^{-2} \sim 1E10^{14}$
LOSS FACTOR ( $\delta$ ) ACCURACY	$< 3E10^{-5}$	$< 3E10^{-5}$	$< 3E10^{-5}$	$< 3E10^{-5}$
SAMPLE DIAMETER (mm)	DEPENDENT ON SAMPLE CELL OPTION		10 to 40	10 to 40
PLATE SPACING (mm)			$1E10^{-6}$ to 20	$1E10^{-6}$ to 20
ANALYZER MODEL	ALPHA-LB	ALPHA-NB	ALPHA-ANB	ALPHA-ATB
SAMPLE CELL	OPTION <sup>*[1]</sup>	OPTION <sup>*[1]</sup>	ZGS	ZGS
SOFTWARE	DETACHEM	DETACHEM	DETACHEM	DETACHEM

[1] BDS 1200 Sample Cell with shielding unit is recommended; Sample Diameter 10mm to 40mm with Plate Spacing of 10um to 20mm

## 5.2 BDS TURNKEY SOLUTIONS: RF & MAGNETIC

### BDS Turnkey Dielectric / Impedance Spectrometers for Ambient Condition with RF Sample Cell

#### ▪ BDS 70



- Covers High Frequency Range from 1MHz to 3GHz
- Sample impedance is determined by coaxial line reflectometry
- RF sample cell consisting of a parallel plate is mounted at the RF impedance analyzer APC-7 impedance port. The sample impedance determines the reflection factor of the sample capacitor, which is measured by the RF analyzer.
- Thin film samples down to 1 $\mu$ m can be measured in a special thin film cell
- If the dielectric sample cell is replaced by a magnetic sample cell, the complex permeability of materials can be measured

#### ▪ BDS 80

- BDS 80 is a combination of BDS 40 and BDS 70 in one system
- System includes Alpha-ANB analyzer with ZGS active sample cell, shielding unit, Keysight E4991B-300 RF Impedance analyzer, BDS 2200 RF sample cell, DETACHEM software and data acquisition unit

**NOTE: System comes with desktop computer complete with single license DETACHEM software installed  
For Temperature Test, refer to Concept Turnkey Solutions for suitable Temperature Control System**

## 5.2 BDS TURNKEY SOLUTIONS: RF & MAGNETIC

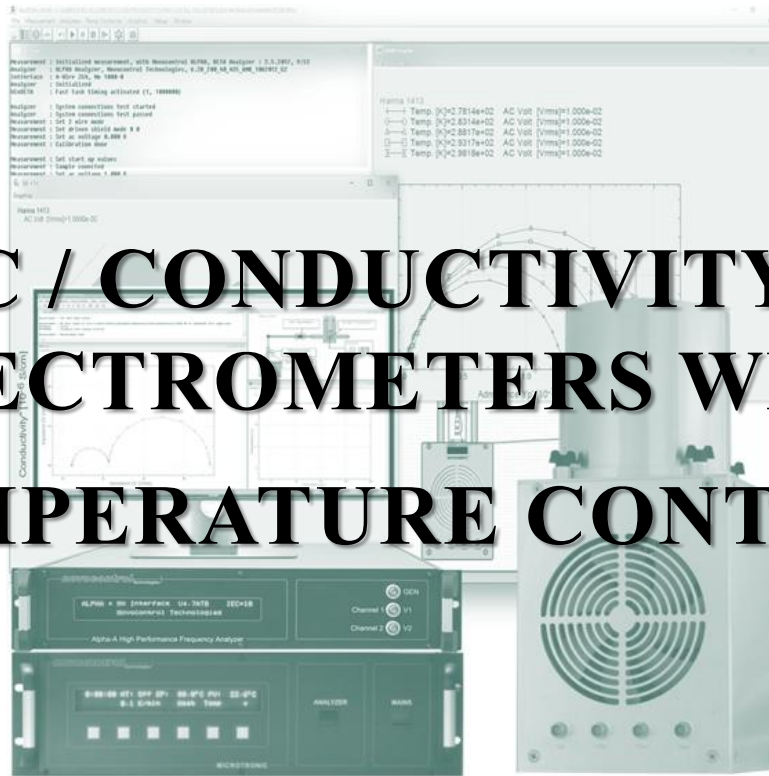
PARAMETER	BDS 70	BDS 80
		
FREQUENCY (Hz)	$1\text{E}10^6 \sim 3\text{E}10^9$	ALPHA-ANB: $3\text{E}10^{-5} \sim 4\text{E}10^7$ KEYSIGHT 4991B: $1\text{E}10^6 \sim 3\text{E}10^9$
IMPEDANCE ( $\Omega$ )	$1\text{E}10^{-1} \sim 1\text{E}10^5$	ALPHA-ANB: $1\text{E}10^{-2} \sim 1\text{E}10^{14}$ KEYSIGHT 4991B: $1\text{E}10^{-1} \sim 1\text{E}10^5$
LOSS FACTOR $\tan(\delta)$ ACCURACY	$< 3\text{E}10^{-3}$	ALPHA-ANB: $< 3\text{E}10^{-5}$ KEYSIGHT 4991B: $< 3\text{E}10^{-3}$
SAMPLE DIAMETER (mm)	3 to 12	3 to 12
PLATE SPACING (mm)	3 to 20	3 to 20
ANALYZER MODEL	KEYSIGHT 4991B	ALPHA-ANB KEYSIGHT 4991B
SAMPLE CELL	BDS 2200 <sup>*[1]</sup>	ZGS / BDS 2200
SOFTWARE	DETACHEM	DETACHEM

[1] Mount directly at the RF impedance analyzer APC-7 impedance port

**NOTE:**

Complex permeability of materials can be measured by replacing the dielectric sample cell with option magnetic sample cells.

# 6. DIELECTRIC / CONDUCTIVITY / IMPEDANCE SPECTROMETERS WITH TEMPERATURE CONTROL



CONCEPT TURNKEY SOLUTIONS

# 6.1 CONCEPT TURNKEY SOLUTIONS

- **Novocontrol Concept Systems in general consist of;**
  - An Impedance Analyzer
  - A Temperature Control System
  - Suitable sample cell/fixture
  - Desktop computer with software installed for control, measurement setup, data acquisition, data management, and data analysis
  - Complete set of vacuum lines (where applicable), measurement cables and interface cables
  - Systems are either desktop or rack-mounted in 19" cabinet
- **Concept 10, 20, 40, 50, 70, 80**
  - Based on the corresponding **BDS systems** in combination with the QUATRO Cryosystem.
  - Temperature Range: -160°C to 400°C
  - Temperature stability:  $\pm 0.01^\circ\text{C}$
  - System mounted in 19" cabinet.
  - Concept 70 and 80 systems include Novocontrol RF Extension



# 6.1 CONCEPT TURNKEY SOLUTIONS

## ▪ **Concept 11, 21, 41, 51, 71, 81**

- Based on the corresponding BDS systems in combination with Novocool Temperature Control System
- Temperature Range: -100°C to 250°C
- Temperature Accuracy:  $\pm 0.3^{\circ}\text{C}$
- System mounted in half 19" cabinet
- Concept 71 and 81 system include Novocontrol RF Extension

## ▪ **Concept 12, 22, 42, 52, 72, 82**

- Based on the corresponding BDS systems in combination with Novotherm Temperature Control System
- Temperature Range: Ambient to 400°C
- Temperature Accuracy:  $\pm 0.1^{\circ}\text{C}$
- Concept 12, 22, 42 are Desktop Systems
- Concept 72 and 82 include Novocontrol RF Extension and are mounted in half 19" cabinet

CONCEPT 41



# 6.1 CONCEPT TURNKEY SOLUTIONS

## ▪ **Concept 16, 26, 46, 56**

- Based on an Alpha-A analyzer and a ZG4 test interface in combination with PHECOS Temperature Control System
- Temperature Range: -45°C to 190°C
- Temperature Resolution:  $\pm 0.1^\circ\text{C}$
- Concept 16, 26, 46, 56 are Desktop systems

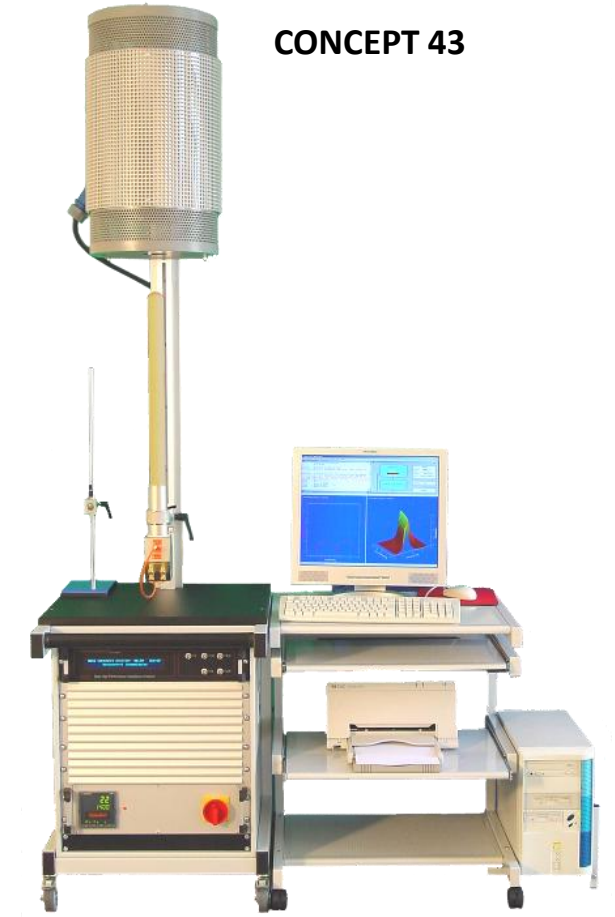
## ▪ **Concept 17, 27, 47, 57**

- Based on an Alpha-A analyzer and ZG4 test interface in combination with PHECOS Lite Temperature Control System
- Temperature Range: -35°C to 150°C
- Temperature Resolution:  $\pm 0.1^\circ\text{C}$
- Concept 17, 27, 47, 57 are desktop systems

# 6.1 CONCEPT TURNKEY SOLUTIONS

## ▪ Concept 43, 44, 45

- Based on an Alpha-A analyzer and ZG4 test interface combination with one of the Novotherm-HT High Temperature Control Systems;
  - Novotherm-HT 1200: Ambient to 1200°C
  - Novotherm-HT 1400: Ambient to 1400°C
  - Novotherm-HT 1600: Ambient to 1600°C
- Temperature Resolution: 0.1 °C
- System mounted in half 19" cabinet





## 7. SPIN COATERS

**Microscopic or Spectroscopic  
Investigations**

## 7.1 SPIN COATERS

- Novocontrol spin coaters enable preparation of thin films easily within a few minutes. The spin coaters consist of an exchangeable chuck driven by a high-speed motor with electronic speed control and an optional vacuum pump.
- Both circular and rectangular substrates can be placed on the chuck where they are held in position by the under-pressure below the substrate created either by a small pump (SCE-150 and SCC-200 models) or by the centrifugal force during rotation (SCI series models).
- The thickness of the film merely depends on the solid/solvent concentration, rotational speed, and time.
- The ergonomic design makes these spin coaters efficient tools for preparation of thin films of organic and inorganic substances for microscopic or spectroscopic investigations. They do not require specific skills or experience and are maintenance free. A built-in digital indicator displays exactly the rotation speed for testing under reproducible conditions.
- By applying rotational speeds up to 18.000 rpm, thin and ultra thin layers of extraordinary homogeneity can be achieved.

# 7.1 SPIN COATERS

## Ordering and Delivery

- Delivery of SCI-225, SCE-150, and SCC-200 models include the spin coater and a switching power supply module (100V/60Hz to 240V/50Hz)
- For the SCI model, the sample substrate size has to match the rotational platform inner diameter. **Rotational platforms** have to be ordered separately and are available with customized inner diameters from 10mm to 40mm. Request for quote and specify upon ordering.
- The SCC-200, SCE-150, and SCR models include one rotational platform of 30mm diameter. 90mm diameter platform is optional. Request for quote for optional item.
- For SCC-200, SCR and SCE-150 models, the MVP vacuum pump is required.

## 7.2 SPIN COATERS: SCC-200

- **Top-Class Microprocessor-Controlled Spin Coater**
  - Rotational speed up to 12,000 rpm
  - Two rotational speed ramps
  - Programmable ramp duration: 3s to 600s
  - Two rotational speed target values
  - Programmable dwell time: 3s to 600s
  - Alphanumeric four-line display (20 characters/line)
  - 10 rotational speed sequences storable in non-volatile memory
  - Display of remaining processing time
  - Total process times: 12s to 40 minutes
  - Active vacuum suction of the sample
  - Film thickness range 10nm to 10 $\mu$ m
  - Rotational platforms for substrates up to 90mm diameter



## 7.3 SPIN COATERS: SCE-150

### ▪ High End Spin Coaters

- Rotational speed up to 9,000 rpm
- Ramp function for the rotational speed
- Programmable ramp duration: 3s to 600s
- Programmable dwell time: 3s to 600s
- Alphanumeric display (20 characters/line)
- Settings stored in non-volatile memory
- Display of remaining processing time
- Total process times: 6s to 20 minutes
- Active vacuum suction of the sample
- Film thickness range 10nm to 10 $\mu$ m
- Rotational platforms for substrates up to 90mm diameter



## 7.4 SPIN COATERS: SCR

### ▪ Economical Spin Coater

- New design (OLED display) and newly developed electronics
- Rotational speed up to 6,000 rpm
- Short ramp with fixed acceleration
- Selected speed stored in non-volatile memory
- Active vacuum suction of the sample
- Film thickness range 10nm to 10 $\mu$ m
- Rotational platforms for substrates up to 50mm diameter





## 7.6 SPIN COATERS ACCESSORIES: MVP, VACCUM PUMP

- **Vacuum pump MVP, Accessory for Models SCE-150 and SCC-200**
  - Under Pressure: -33.3 kPa
  - Flow: 7 litres/min
  - Noise Level: 40 dB(A)
- Due to a novel design of the rotational platform, the substrate is to be held tightly on which the sample is to be deposited



**THANK YOU FOR YOUR ATTENTION**

**LOOKING FORWARD TO YOUR SUPPORT**