

**EFCF EIS Tutorial**

# **Electrochemical Impedance Spectroscopy Tutorial**

by Tutors

**Dr. André Weber**

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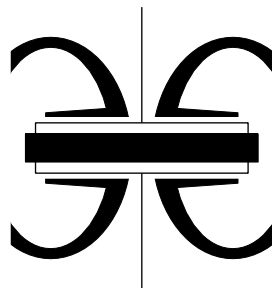
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## Tutors

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**L2: Evaluation of Impedance Spectra  
Kramers-Kronig Test, DRT-Analysis & CNLS Fit**

**L3: Applications I:  
Analysis of Materials and (Model-) Electrodes**

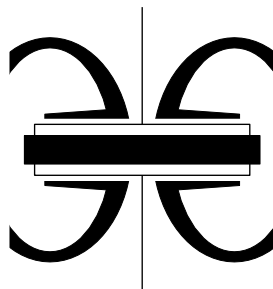
**L4: Applications II - Analysis of Single Cells and Stacks**

**L5: Impedance Modelling and Simulation**

**L6: „EIS challenge“-Summary**

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**Visit of the EFCF exhibition**



# TUTORS

**Dr. André Weber**



Dr. André Weber is a senior researcher (Akademischer Oberrat) at the Institute for Applied Materials (IAM-WET) at Karlsruhe Institute of Technology (KIT), Germany, where he heads both the fuel cell and battery research groups. In addition, he acts as scientific manager of the “Fuel Cell Test Laboratory” since 2002, a joint lab of KIT and the European Institute for Energy Research (EIFER), designated for the testing of fuel cell systems.

After studying electrical engineering at RWTH Aachen university and a stay at Siemens Central Research, Munich (Germany), where he became acquainted with Ellen Ivers-Tiffée, he obtained his PhD at Universität Karlsruhe (TH), now KIT, in 2002. During this time he was strongly involved in the establishment of the SOFC group at IAM-WET. He has collaborated with many groups in numerous national, European and international research projects since 2000.

His research is related to the electrical testing and modeling of fuel cells and batteries, with a special emphasis on the detailed characterization by means of electrochemical impedance spectroscopy. The experimental and theoretical work of his research groups ranges from fundamental studies on model systems to the analysis of commercial products, aiming at an understanding of the complex coupling of electrochemical reactions and transport mechanisms in electrochemical devices.

André Weber has authored or co-authored several book chapters, 80 conference proceedings and more than 100 peer-reviewed journal papers on scientific topics related to fuel cells and batteries.

[www.iam.kit.edu](http://www.iam.kit.edu)

**Dr. Dino Klotz**



Dr. Dino Klotz is a postdoctoral research associate at the International Institute for Carbon Neutral Energy Research (I2CNER) at Kyushu University, Fukuoka, Japan.

He obtained his PhD in 2012 at KIT, in the group of Ellen Ivers-Tiffée, where he was an active member of the SOFC group, mostly dealing with impedance measurements, modeling and analysis.

From 2013 to 2015, he was a post-doc in Prof. Shikazono's group at the University of Tokyo, where he analysed composite cathodes for SOFCs. After that, he joined Prof. Rothschild's group at the Technion in Haifa, Israel, where he established new photoelectrochemical impedance techniques and analysis methods on hematite photoanodes for solar water splitting. He recently returned to SOFC research at I2CNER, where he applies optical impedance techniques to probe the surface exchange process on model thin film cathodes. This work is in collaboration with Prof. Tuller's group at the MIT in Boston.

Dino Klotz has authored more than 40 publications with a strong focus on impedance measurement, analysis and modeling. He has been a tutorial instructor for the EIS tutorials at the MRS fall meeting 2016 and SSI conference in 2017.

<http://i2cner.kyushu-u.ac.jp>

# Table of contents (Details)

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## **L1: Fundamentals of**

### **Electrochemical Impedance Spectroscopy**

- Impedance measurements
- Selection of appropriate testing parameters
- Impedance analyzers
- Impact of wiring and cell setup
- Correction and calibration

## **L2: Evaluation of Impedance Spectra**

### **Kramers-Kronig Test, DRT-Analysis & CNLS Fit**

- Validating impedance data quality
- Distribution of Relaxation Times (DRT)
- CNLS-fit

## **L3: Applications I:**

### **Analysis of Materials and (Model-) Electrodes**

- Electronic, MIEC and ionic conductors
- Grain and grain-boundary resistivity
- Single electrode measurements – ideal counter electrode, symmetrical cell or reference electrode
- High resistance model electrodes
- High performance electrodes

## **L4: Applications II - Analysis of Single Cells and Stacks**

- Single cell tests
- Repeat unit tests
- Stack tests

## **L5: Impedance Modelling and Simulation**

- Electrochemical processes and their operating parameter dependencies
- Deconvolution of electrode processes
- From ac-impedance to dc-performance

## **L6: „EIS challenge“-Summary**

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# European Fuel Cell Forum - EFCF



The **sole purpose** of the European Fuel Cell Forum is the promotion of fuel cell and hydrogen technologies through the EFCF conferences, expositions, promotion events (Green Salon & Rondo), literature and media. It is an enabling, high level exchange platform, providing scientific sessions and tutorials, a technical exhibition, as well as international project meetings and recreational networking events in the charming and inspirational area of **Lucerne, in the heart of Switzerland**. Every summer the **EFCF invites more than 10'000 stakeholders** around the world to participate in this internationally recognised event on the shores of the picturesque lake Lucerne.

The EFCF has a heritage of more than 24 years! As **far back as 1994** the 1st EUROPEAN SOFC FORUM attracted leading international speakers as well as a global audience. Since then, a high quality conference series has been established. It grew to the **EUROPEAN REFERENCE EVENT in the field**, where the ENTIRE COMMUNITY likes to meet. The conference topics alternate annually. On even years the conference concentrates on **«Solid Oxide Cells» (SOC): Fuel Cells, Electrolysers and Membrane Reactors**. On odd years, the conference concentrates on **«Hydrogen Fuel Cell and Direct Alcohol Fuel Cell» as well as «Hydrogen Processing: Production, Storage and Infrastructure»**.

Unlike many commercial conferences, the **EFCF is organised by FCH technologists and scientists**. The owners Olivier Bucheli and Dr. Michael Spirig are active members of the European FCH community. Comprehensive exchange of scientific and technical information and high-level networking are the main objectives. Dedicated to continuously grow the EFCForum as one of the most prominent and interesting meeting places. To ensure a permanent progress the recommendations of the **renowned EFCF International Board of Advisors** are considered and the trends of the sector observed and anticipated ([www.EFCF.com/IBoA](http://www.EFCF.com/IBoA)). The organisers ensure that the stakeholders needs are always the focus of the EFCF, with the ambition to build a **Bridge from Science to Technology and from Technology to Products!**

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Olivier Bucheli



Michael Spirig



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