Climate
In situ TEM gas and heating

Quantum Design EUROPE

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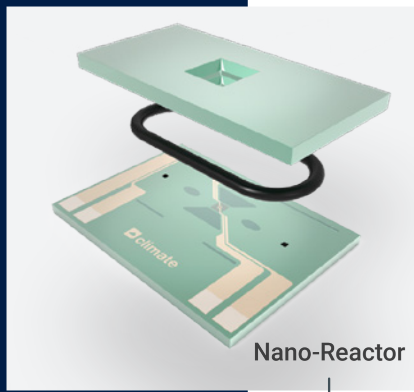
Introduction

The Climate In Situ TEM Gas & Heating Solution enables the atomic resolution imaging of gas-solid interactions and sample dynamics in research areas such as catalysis, nanomaterials growth and corrosion studies.

Climate will convert your high vacuum TEM from a static imaging tool into a real-world research laboratory, enabling you to speed up your development of new catalysts or other energy-relevant materials and techniques.

Climate is the only environmental solution in the market that allows full dynamic correlation of structural and chemical data. This includes reaction-product analysis due to the integration with the optional dedicated DENSsolutions Gas Analyzer.



Sample holder

The DENSsolutions **Gas Analyzer** enables the analysis of reaction products, transforming Climate into a unique platform able to combine TEM-based data with information about the reaction kinetics.

The DENSsolutions Climate **Vaporizer** elevates your in situ experiments by enabling you to independently add water vapor to any gas mixture. Ultimately, you can work with and even humidify 3 different types of gases at once.

Typical applications

Heterogeneous catalysis

Materials synthesis and growth

Corrosion of metals & alloys

Green energy materials

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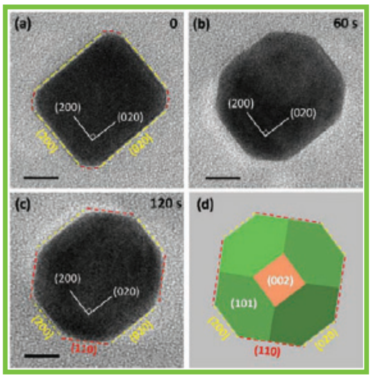
Selected Publications



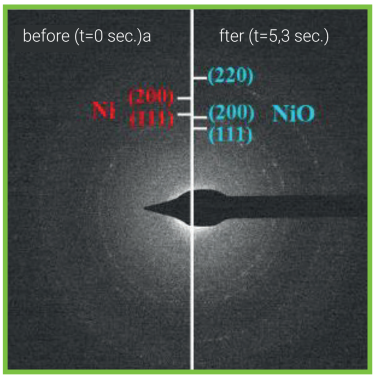
Time resolved in situ TEM images demonstrate the shape evolution of a Pd nanochrystals under 1 bar O_2 at 200 °C and the rebuilt Pd equilibrium structure by calculations. Scale bar: 5 nm.

Nanocrystal shape evolutions

The Climate customers demonstrate an atomic scale TEM observation of shape evolutions of Pd nanocrystals under oxygen and hydrogen environment at atmospheric pressure. Combined with multi-scale structure reconstruction model calculations, the reshaping mechanism is fully understood.

These results give a direct insight into the behavioural response of nanoparticles to a 'real' reactive pressure environment, which is likely to improve the understanding of solid-gas reaction during catalytic applications.

Zhang, Xun et al. Chemical Communications 53 (2017) 13213-13216



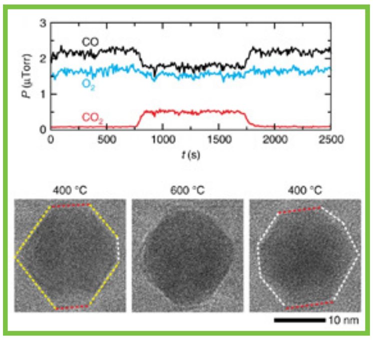
In Situ selected area electron diffraction (SAED) images. In Situ conditions: T = 600 °C, 200 mbar O2, 800 mbar N2, Flow = 0,6 ml/min. .

Nanoparticle reaction kinetics

Acquiring the kinetics of gas-nanoparticle fast reactions under ambient pressure is a challenge owing to the lack of appropriate in situ techniques. Using our Climate system and time-resolved in situ electron diffraction, the researchers develop a new approach that allows quantitative structural information to be acquired under ambient pressure with millisecond time resolution.

They were able to vividly obtain the ultrafast oxidation kinetics of Ni nanoparticles in oxygen. Ultimately, this study gives new insights into Ni oxidation and paves the way to study the fast reaction kinetics of nanoparticles using ultrafast in situ techniques.

Yu, Jian et al. Angewandte Chemie (2018)



The measurements of the CO, O_2, and CO_2 content in the outlet gas stream during the experiment. The TEM images show the sequence describing the morphological changes in a Pd nanoparticle at different temperatures.

Thermal catalysis

The availability of active sites on a catalyst's surface determines its dynamical structure. However, the way that nanoparticle (NP) catalysts re-structure under reaction conditions and how these changes relate to the catalytic activity is not yet fully understood.

Using Climate and operando transmission electron microscopy, the authors find that palladium NPs show reversible structural and activity changes during heating and cooling in mixed gas environments containing O_2 and CO. Conclusively, these results show how gas environments can alter the structure of NPs, even at relatively low temperatures and have important implications for our understanding of how CO adsorption can affect NP surfaces.

Chee, See Wee et al. Nature Communications 11 (2020) 2133

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Why Climate?

1

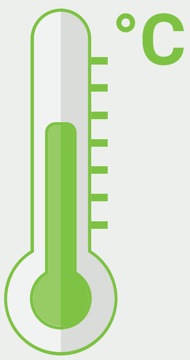
State-of-the-art environmental control

1. Dynamic mixing
Our patented mixing valve enables you to change the gas composition on the fly.

2. Fast switching
Alter the gas environment within seconds.

3. Independent control
Independently control gas composition, pressure and flow rate with a wide experimental range.

2

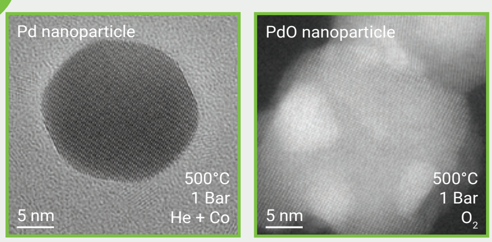


Accurate temperature control

1. Temperature accuracy and stability in gas environment
4-point probe heating provides the most accurate temperature control even during dynamic conditions.

2. Acquire calorimetry data
Monitor heat dissipation and absorption during endo- or exothermic reactions with high sensitivity.

3



Reliable experiments

1. Predefine the experimental conditions
Define your optimal experimental conditions before using the TEM by attaining ex situ mass spectrometry data with Climate.

2. High stability
Achieve atomic resolution in TEM and STEM in static and flow modes.

3. Optimized analytical capabilities
The optimized design enables EELS and large solid-angle EDS collection.

4. Clean experiments
The modularity of the holder enables easy on-site exchange and cleaning of all critical components.

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Software for integrated control and data

Impulse 1.1

Intuitive In Situ experiment control and automation software

Impulse 1.1 grants you complete control over your stimuli. It offers an integrated control interface that is flexible to adapt to your experiment. You can even design your In Situ experiment from your desk. Decide which sample conditions you want to be met at which time and Impulse will do the rest.

Smart automation

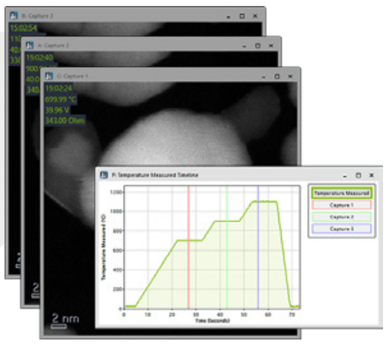
- Easily design your experiment with the drag-and-drop profile builder.
- Smart automation keeps track of measurements and ensure that your sample conditions are met.
- Accurately reproduce your experiments.

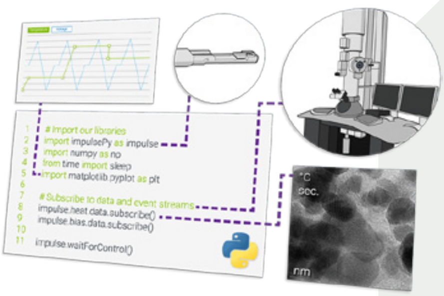
Flexible dashboard

- Plot any number of parameters that are important for your experiment.
- Arrange and resize the graphs so that you never miss a thing.
- Quickly find correlations and make real-time decisions.

Data integration

- Synchronize your stimuli data with other data from your experiment.
- Provide your camera and detector images with stimuli annotations in seconds.





Experimental freedom

- The Impulse application programming interface (API) and Python module lets you control your system using Python scripts. This offers unbound freedom in experiment control.
- Automate and synchronize data collection of cameras and detectors with the control of the stimuli.

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System specifications

	Climate Air	Climate GVB	Climate G+
Heating control mode	4-point probe resistive feedback		
Heating range	RT - 1,000 °C		
Heating & cooling rate	Up to 150 °C/sec		
Temperature stability	≤ ± 0.01 °C		
Pressure range	Ambient	0 - 1,000 mbar	0 - 2,000 mbar
Resolution*	≤ 100 pm		
Drift rate*	≤ 0.5 nm/min		
Modular holder design	Yes		
On-chip flow channel	Yes		
Mass Spectrometer	0 - 200 AMU		
Gas mixing method	N/A	Discrete	Continuous
Mixing flammable mixtures	N/A	No	Yes
Gas switching	N/A	Up to 10 min	≤ 15 sec
Gas input lines	N/A	3	3
Gas flow range (normalised)	Static	0 - 1 ml/min	
Micro-calorimetry	Yes		
EDS compatibility**	Yes		
EELS compatibility	Yes		

** Depending on microscope configuration*
*** Depending on pole piece geometry and EDS configuration*

JEOL	Climate Air	Climate GVB	Climate G+
Modes	TEM, STEM, EDS, EELS, diffraction		
Alpha tilt range*	UHR, FHP = limited, HRP ≥ ±15 deg, WGP ≥ ±21 deg		

** Depending on microscope configuration*

Thermo Fisher Scientific	Climate Air	Climate GVB	Climate G+
Modes	TEM, STEM, EDS, EELS, diffraction		
Alpha tilt range*	C-TWIN, TWIN ≥ ± 35 deg, X-TWIN, S-TWIN ≥ ± 25 deg		

** Depending on microscope configuration*

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Complete ‘plug & play’ package

1. Climate TEM specimen holder
2. Nano-Reactor starter pack
3. Heating control unit*
4. Laptop with pre-installed software
5. Chip alignment setup
6a. Gas Supply System for Climate GVB
6b. Gas Supply System for Climate G+
7. Vaporizer (optional)
8. Gas Analyzer (optional)

** Integrated inside the GSS for Climate GVB and G+ (6a. and 6b.)*

Including:
Supporting tools

Service and Support

Product warranty	24 months with optional extension
Regulatory compliance	CE, RoHS, FCC
Radiation safety	According to TEM manufacturers compliance regulations

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To find your local distributor, please visit:
www.DENSsolutions.com/distributors

Wildfire
Heating

Lightning
Heating + Biasing

Climate
Gas + Heating

Stream
Liquid + Biasing or Heating

Version 3.0

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