

Company Profile Sintering Technology

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FCT Systeme GmbH, Rauenstein

Outline

- **Company Profile**
 - **FCT Group - History and Business Areas**
 - **FCT Systeme GmbH**
 - **History**
 - **Philosophy**
 - **Portfolio**
- **FCT Rapid Sintering Technology “FAST”**
- **FCT Systeme Technical Center**
- **Course of a Typical Customer Development Project**



History of the FCT Group

- 1982** **Nucleus of FCT Group: Foundation of KCE Sondermaschinen GmbH by Heinz U. Kessel**
Development and manufacturing of sintering plants for the production of engineered ceramics
- 1985** **FCT Fine Ceramics Technologies**
The technology venture to KCE. During the 1980's, KCE and FCT made their mark by manufacturing the largest induction-heated sintering plant (1985) and the most powerful hot press (1989) to date
- 1994** **Foundation of FCT Hartbearbeitungs GmbH**
Development and finishing of components made from engineered ceramics
- 1996** **Foundation of FCT Ingenieurkeramik GmbH**
Manufacturing of ceramic high-performance materials and composites
- 1996** **Foundation of FCT Systeme GmbH**
as direct successor to KCE Sondermaschinen GmbH
- 2002** **Development of the first HP D plant**
a new and powerful plant type based on the technology of field assisted sintering (FAST)
- 2003** **to 2011 Development and delivery**
of 68 customised plants for the manufacturing of solar-grade silicon for leading solar companies
- 2012** **Development of the most successful hybrid concept**
Combined FAST/SPS and hot pressing in one plant
- 2016** **Launch of new multi purpose sintering units with flash sintering option**
New options for material development and production



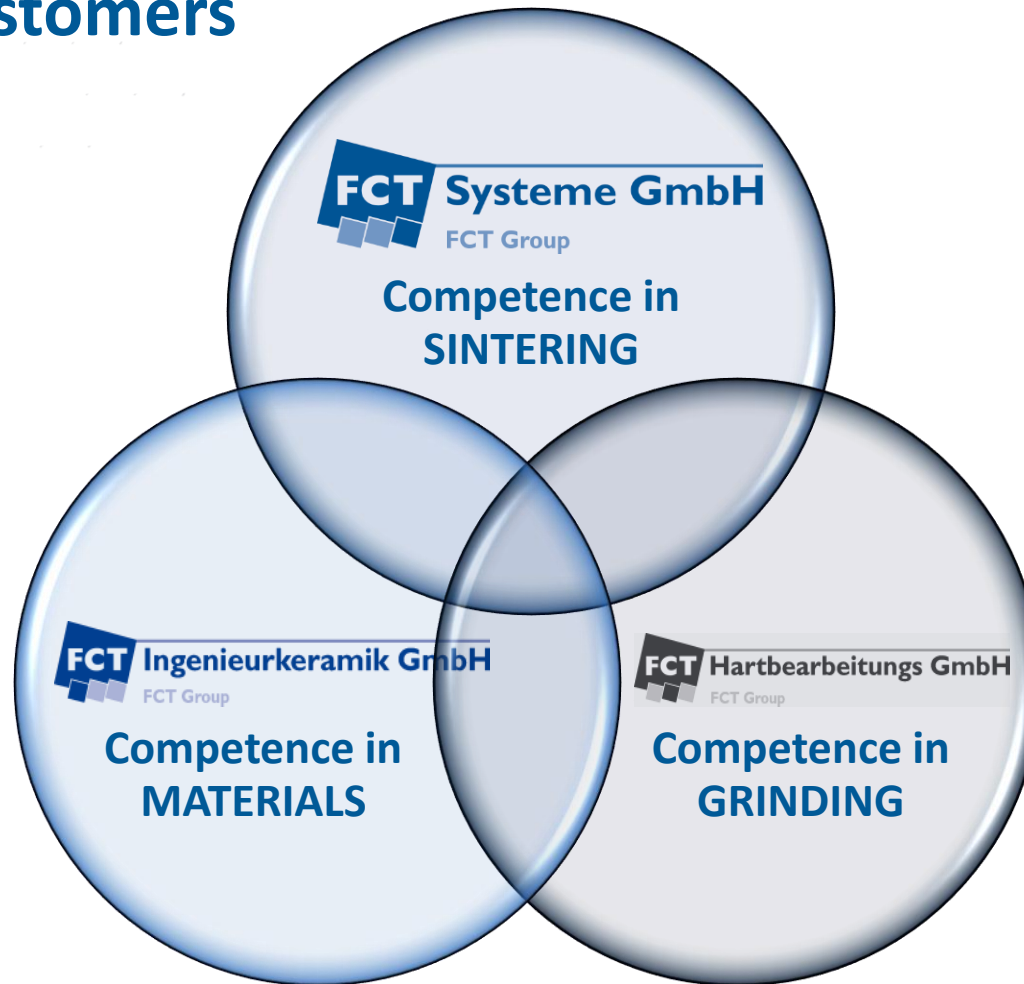
1st hot press 1970 :

- Vacuum / Gas
- Highest Temperatures



The FCT-Group:

Interdisciplinary, Professional Support and Consulting
for our Customers

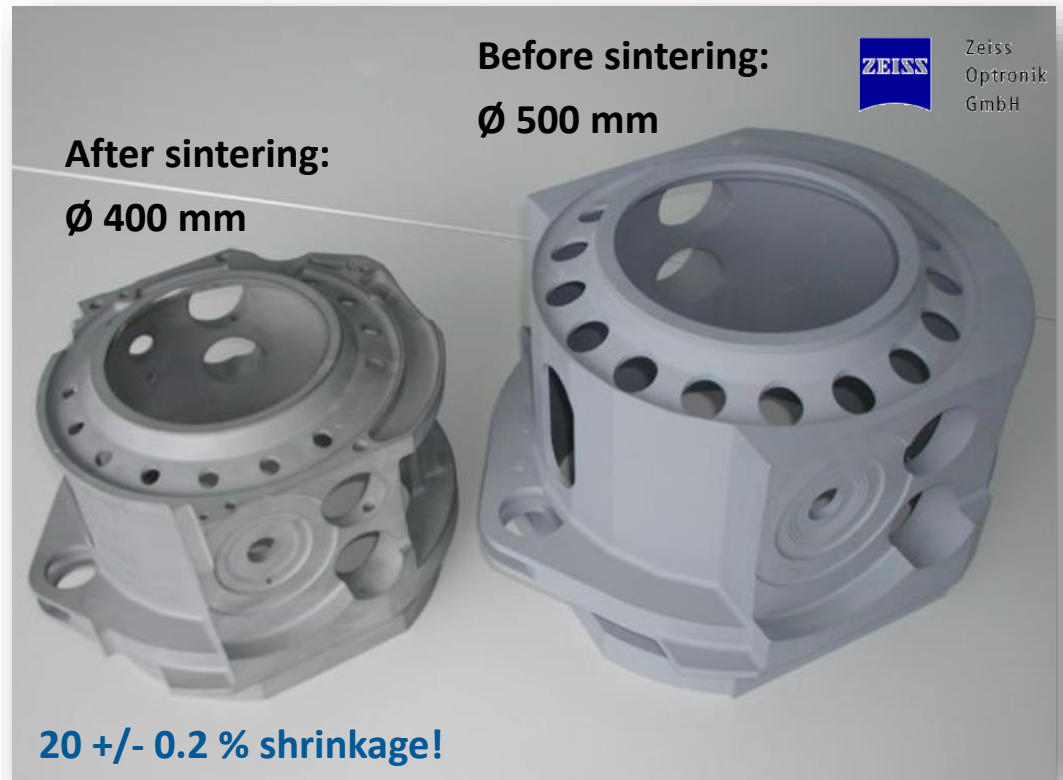


190 Employees - 25 Mio€ Turnover (2016)
2017-05-23_FCT_Company + FAST DHE.pptx

Specialty: Large Si_3N_4 Parts, Complex Geometry

Surveillance Camera Housing (gas-pressure sintered Si_3N_4)

Highest precision and expertise required for green machining, sintering and final machining!



Specialty: Large Si_3N_4 Parts, Complex Geometry

Surveillance Camera Housing (gas-pressure sintered Si_3N_4)



Specialty: Large Si_3N_4 Parts, Complex Geometry

Surveillance Camera in Action



THALES

FCT Ingenieurkeramik GmbH
FCT Group



Zeiss
Optronik
GmbH

Specialty: Large SiC Parts, Complex Geometry

Large-sized Milling Cylinder (SSiC)

- Diameter: 500 mm
- Height: 700 mm
- Weight: 70 kg (SiC)
For comparison: 320 kg (WC)
- Probably the largest-volume component ever achieved from sintered silicon carbide



- A company of the FCT group located in Rauenstein, community of Frankenblick, Federal State of Thuringia.
- Active in the field of high performance sinter materials, as innovative systems provider and machinery manufacturer.



FCT Systeme GmbH – High-Temperature Equipment and Technology

- **Founded in 1996 as Part of the FCT Group**
- **Successor of KCE Sondermaschinen GmbH Founded in 1982**
- **55 Employees**
- **15% of Current Employees Active in the Field of Research and Development.**
- **Export quota close to 90%.**
- **More than 600 High-Temperature Furnaces Sold to Customers Worldwide**
- **100% Family Enterprise**
- **Growth and Independence by 100% Private Equity Financing**
- **12.6 Mio€ Turnover (2016)**



FCT Systeme GmbH –

Not only a simple furnace manufacturer, but:

- Highly advanced technologies
- Well-equipped technology center:
 - Own pilot plant arrangements
 - Experienced team of technicians, engineers, and scientists
 - Continuous development and improvement of advanced system concepts and sintering processes.
 - Customer Projects to Support Customer's Developments:
Idea → Sample → Prototype → Pilot plant → Serial production technology
 - Close and long-term collaborations with universities and research organizations worldwide and in the frame of national or European funded R&D joint projects
- Well protected customer IP by NDA
- "Turn-key" projects from the raw material to the finished product
- Premium after-sale service



FCT Systeme GmbH –

National and International R & D Project Work

 **FAST 2002 - 2006**

 **3DTP 2003 – 2004**

 **THENOX 2004 – 2007**

 **NANOPAL 2005 – 2007**

 **SPEED 2005 - 2008**

 **NANOKER 2005 – 2009**

 **VERDAMPFER 2006 – 2009**

 **HPMat 2006 – 2009**

 **nanoHM 2008– 2011**

 **SintMMC 2008 – 2011**

 **ENITEC 2009 - 2012**

 **FASTool 2010 – 2011**

 **WINDROLLER 2010 – 2013**

 **CoolSemiko 2011 – 2013**

 **ZirStaFol 2011 – 2013**

 **SeProFAST 2011 – 2014**

 **PowerDriver 2012 – 2014**

 **nanoRec 2013 – 2016**

 **HyMaCer 2013 – 2015**

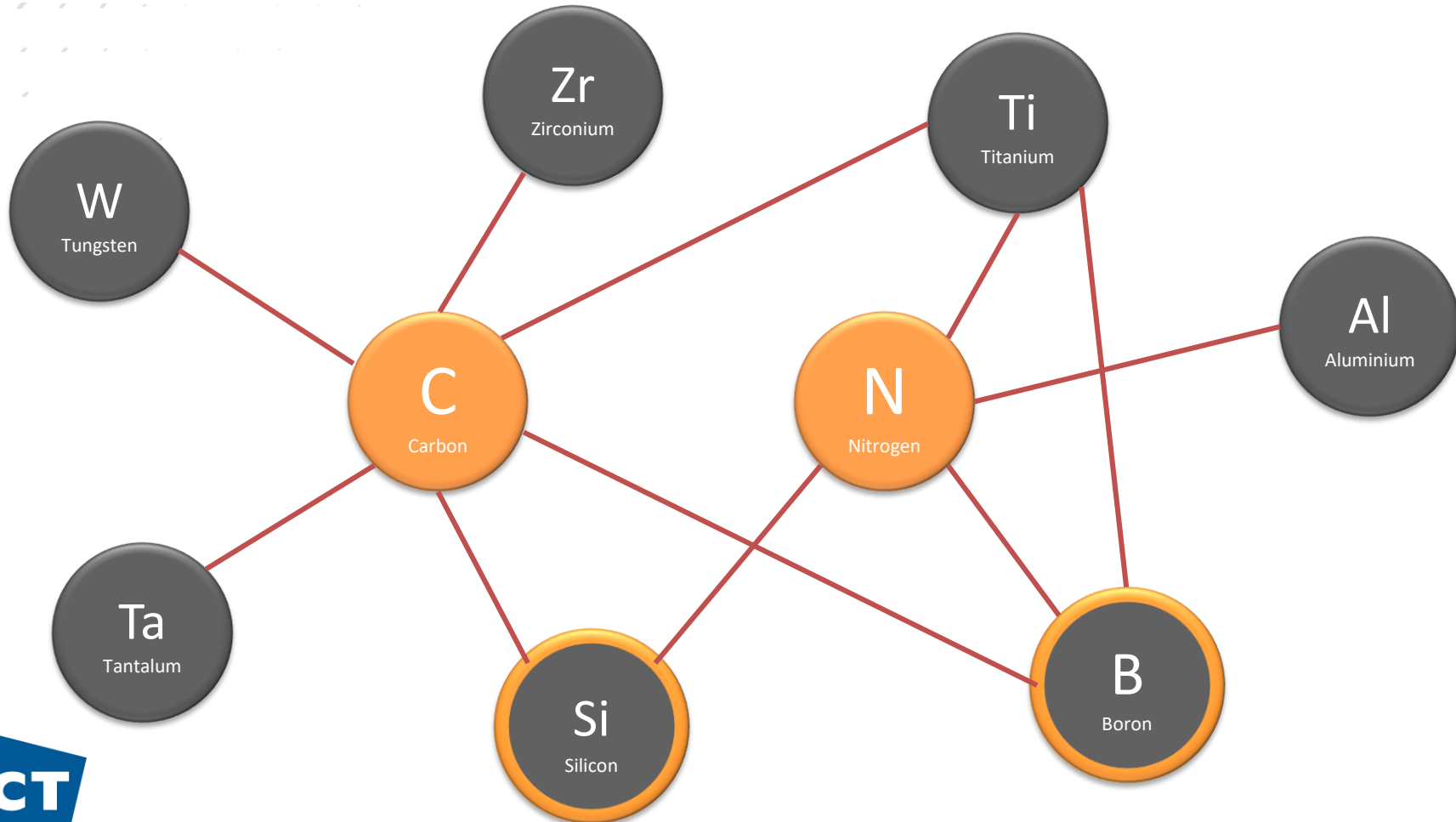
 **KoniFere 2013 – 2016**

 **AeroFurnace 2017-2019**



The FCT-Concept:

- **Non-Oxide Engineering Ceramics**
Nitrides, Carbides and Borides



The FCT-Concept:

- **Non-Oxide Engineering Ceramics**
Nitrides, Carbides and Borides
- **Ceramic Matrix Composites CMC**
BN/TiB₂, Al₂O₃-SiC_w, ZrO₂-Ti(C,N), ...
- **Powder-Metals**
W, Mo, Al-Si-Zr-..., Nd-Fe-B, Zr-Hf-Co-Sb-Sn-...
- **Metal Matrix Composites**
WC/Co, Al-SiC, Al-C_f, TZM, ...
- ...



FCT Systeme GmbH – High-Temperature Equipment and Technology



**Vacuum
Sintering
Furnaces**

**FH W /
FSW**



**Gas
Pressure
Sintering
Furnaces**

FPW



**Hot
Presses**

HP W

**and mould
technology**



**FAST/SPS-
Furnaces**

**(Field Assisted
Sintering/
Spark Plasma
Sintering)**

**HP D /
H-HP D**

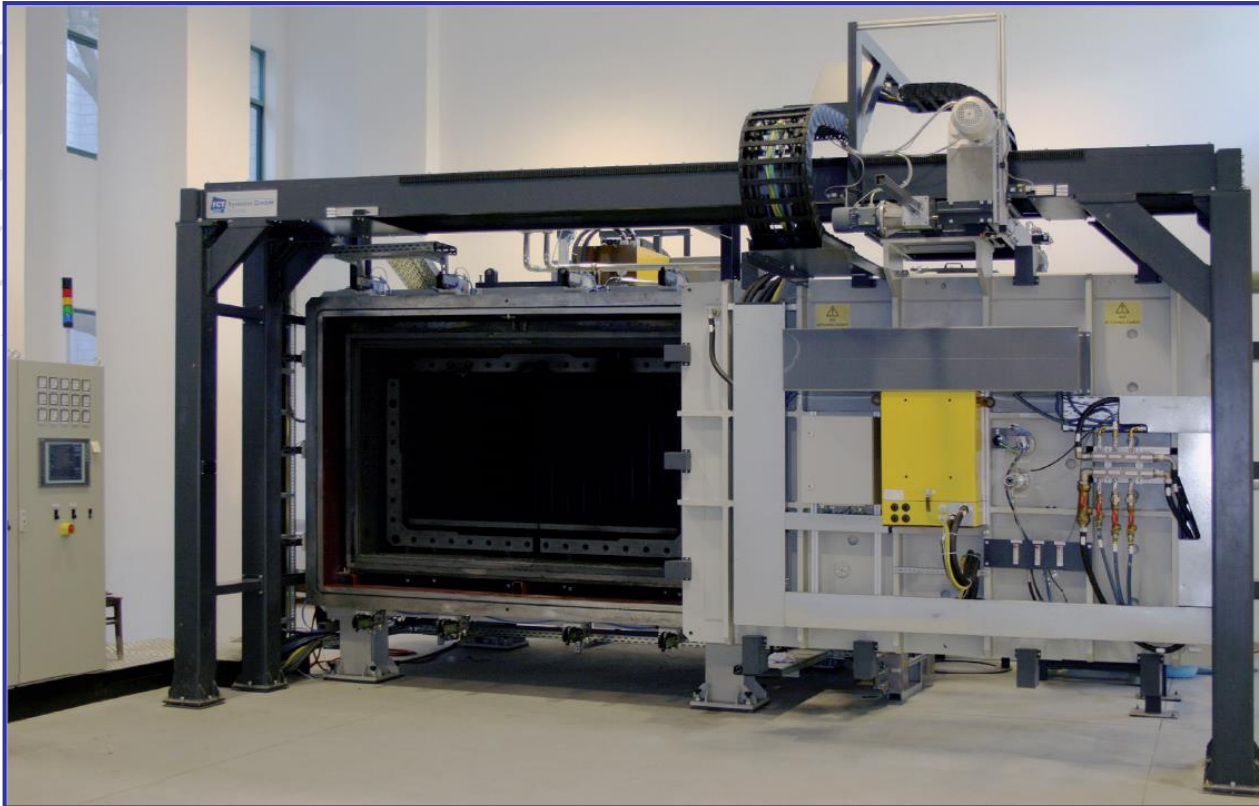


**Customized
Solutions**

CVD/CVI



Advanced Vacuum Sintering Furnace (FH W 4000)



- Useful Volume 4.8 m³
(2200x2400x1100 mm)
- 2200 °C
- 10⁻² mbar
- Ar / N₂ / He

Twin Vacuum Sintering Furnace (FH W 1750)



- Useful volume 600 dm³ (500x480x2500 mm)
- 2200 °C
- 10⁻² mbar
- Ar / N₂ / He
- Debinding 50 kg/h
- Rapid cooling with heat exchanger



Gas Pressure Sintering Furnace (FP W 300-SD)



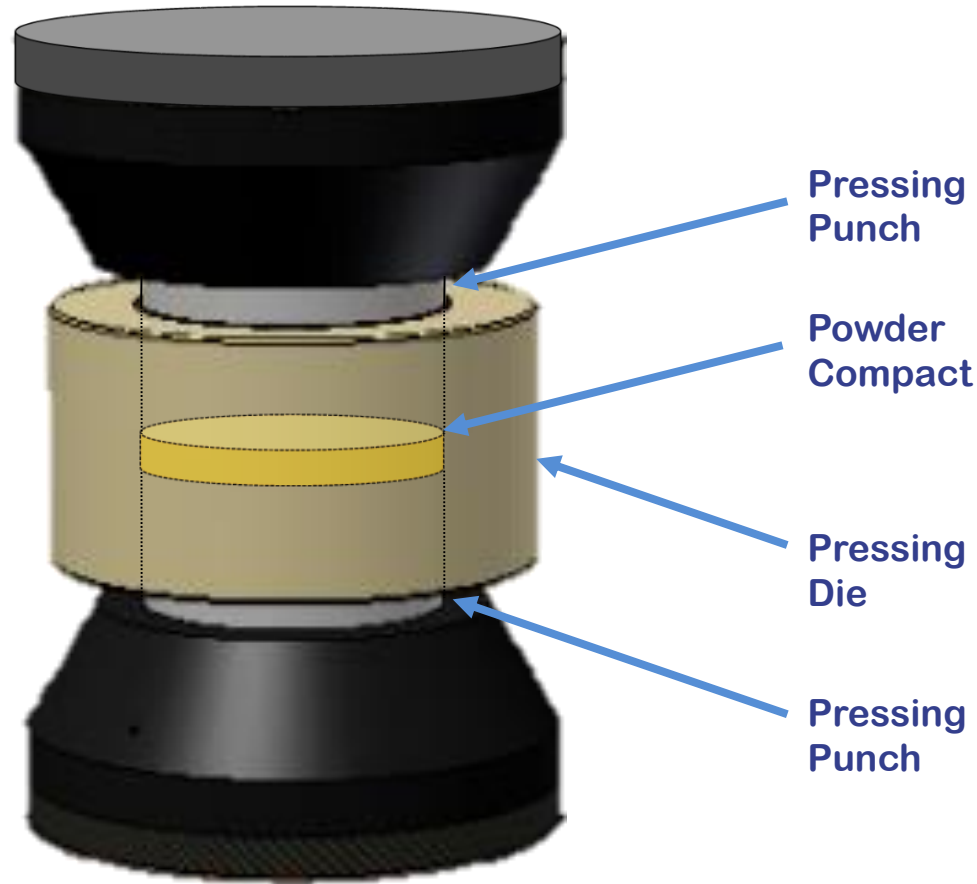
- Useful volume 300 dm³
- 2200°C
- 10 MPa
- Ar / N₂ / He

Production Hot Press System (H-HP W 400-HP)



- 2200°C
- 4000 kN
- 5×10^{-2} mbar
- Ar / N₂ / He
- High pressure up to 10 bar
- Rapid cooling
- High temperature homogeneity
- Loading device

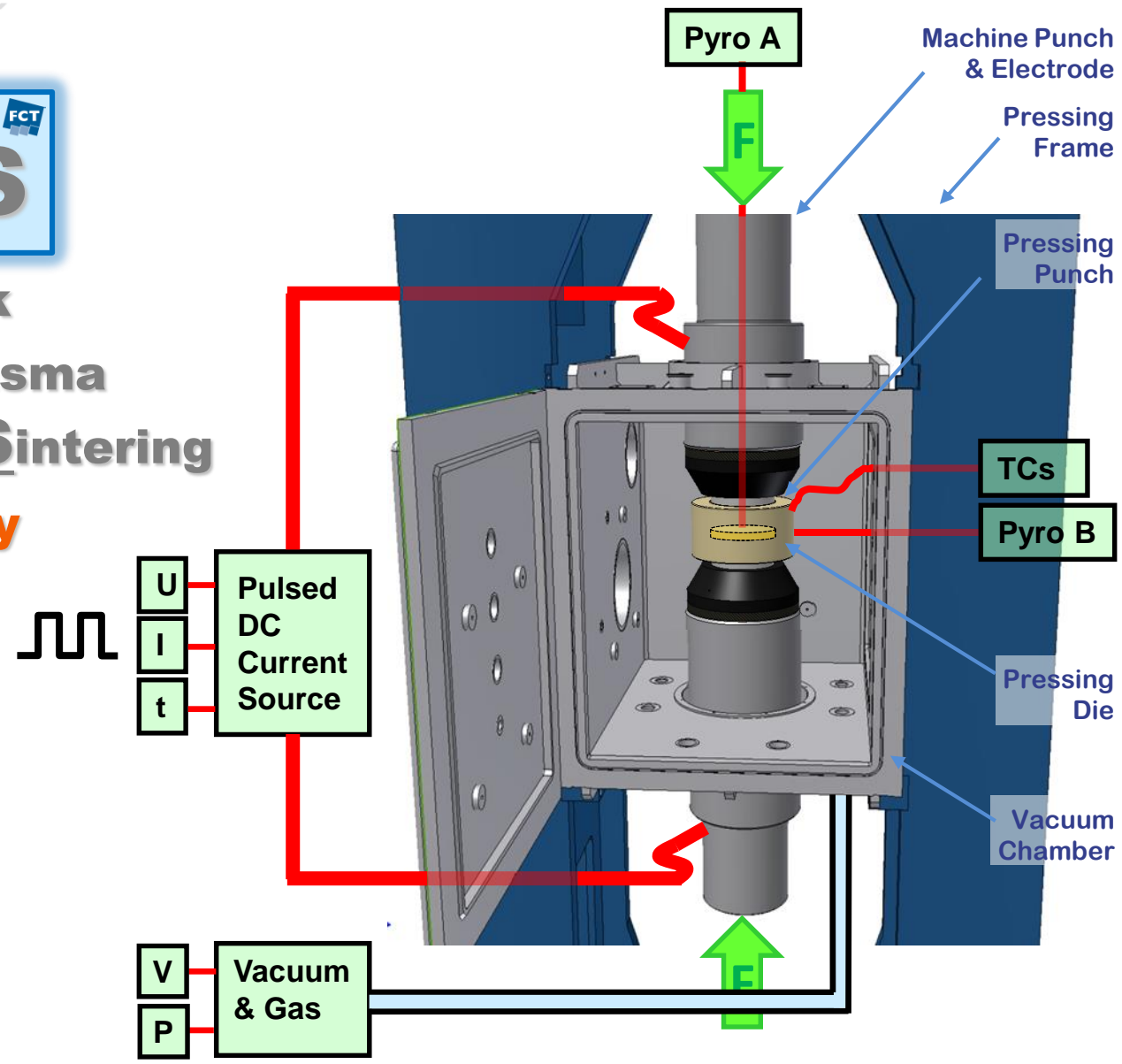
FAST / SPS : Rapid Sintering of a Powder Compact



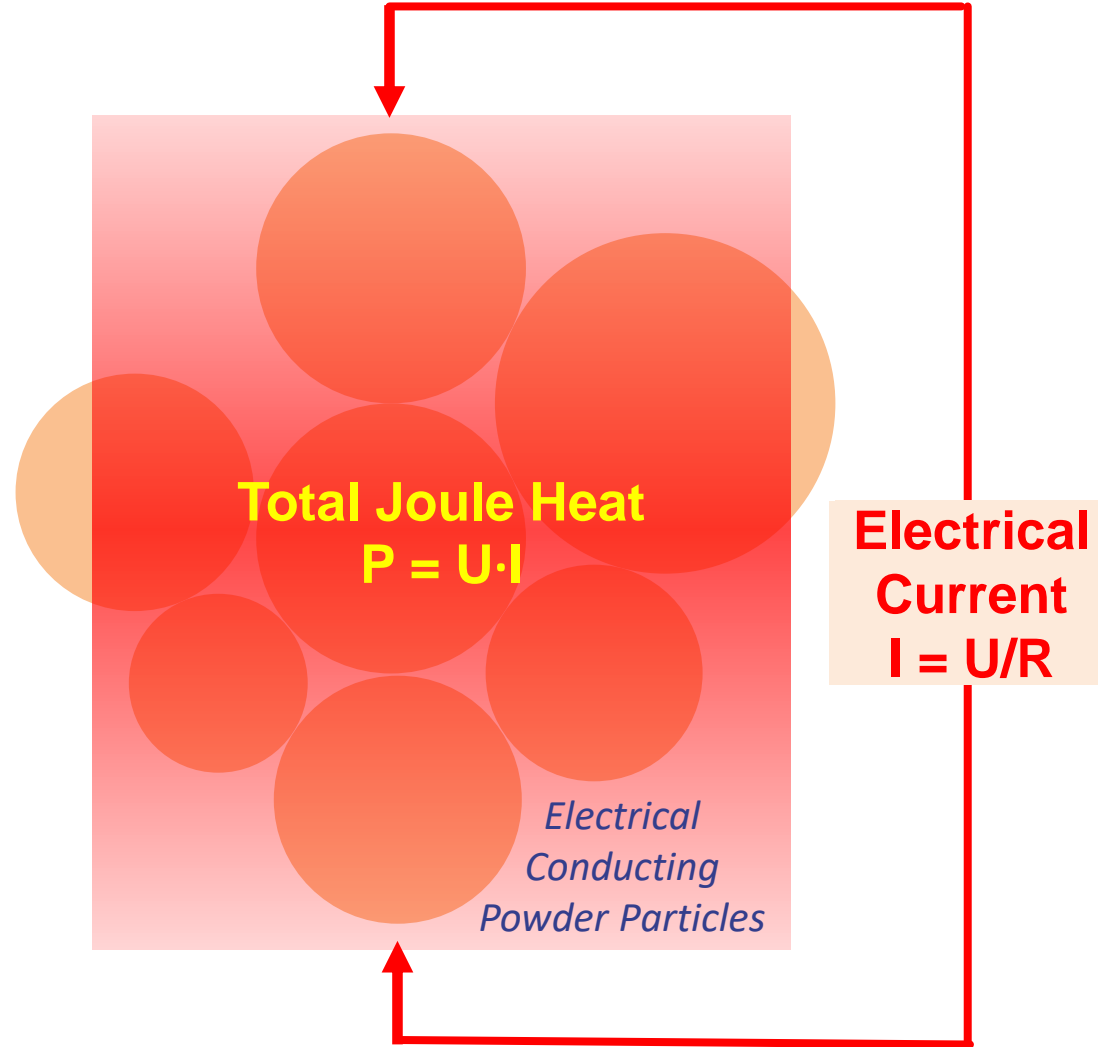
FAST / SPS : Functional Principle

FAST SPS FCT

Field Assisted Sintering Technology
Spark Plasma Sintering



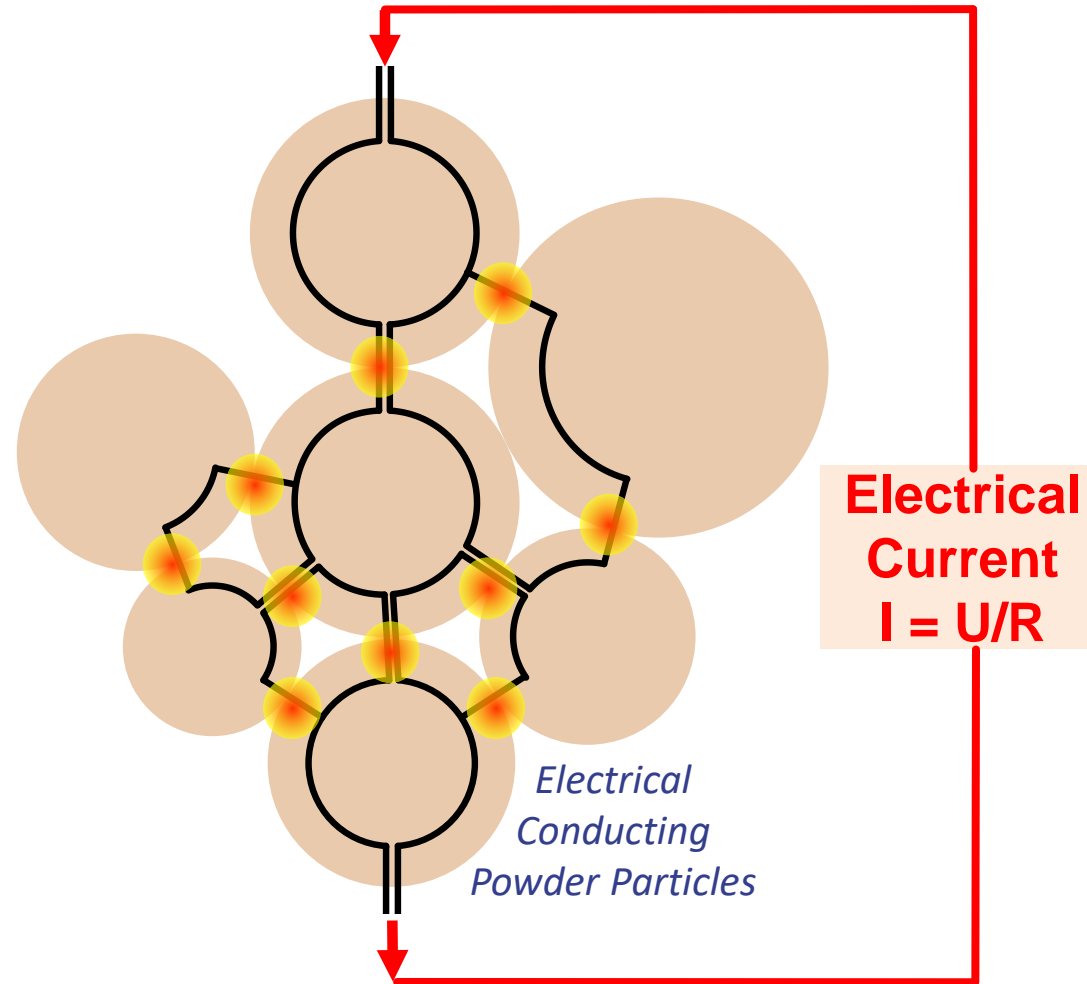
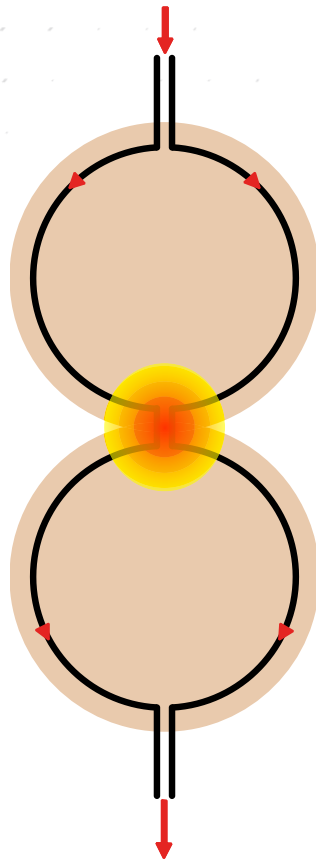
Potential Field Effects Assisting Sintering



Potential Field Effects Assisting Sintering

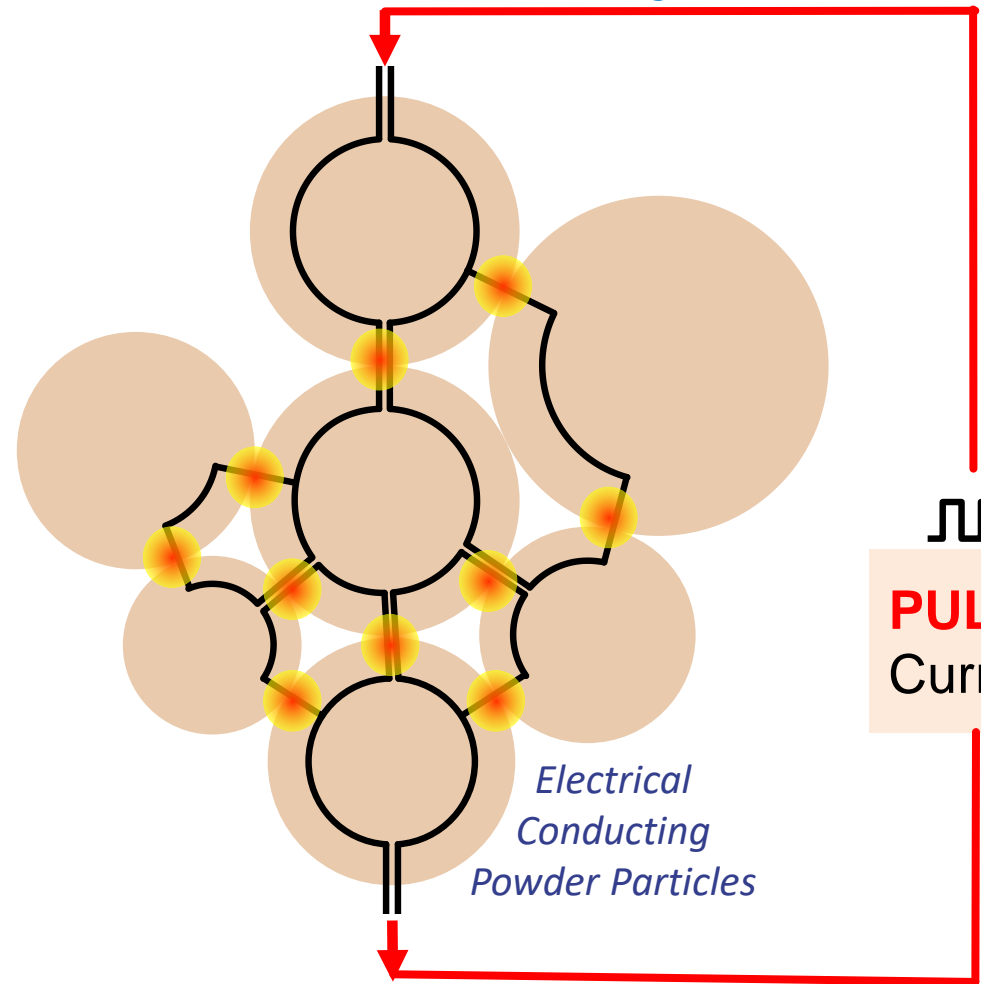
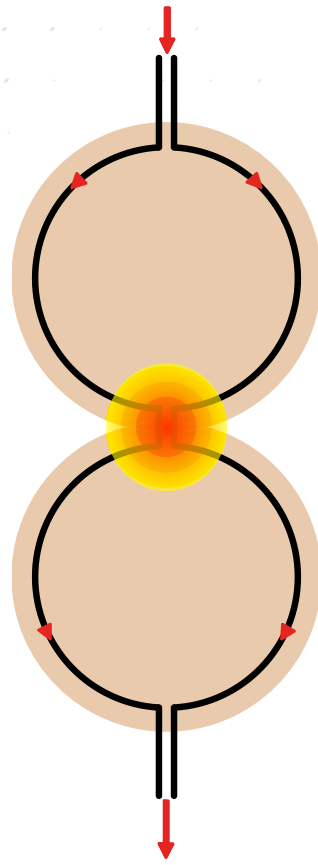
$$\text{Joule Heat} = f(\text{Current DENSITY})$$

High Current Density at Particle Contact = **Locally Boosted Heating**



Potential Field Effects Assisting Sintering

PULSE Current = **PEAK** Current Density




PULSE
Current

*Electrical
Conducting
Powder Particles*

High
PEAK
Current
Density
=
PEAK
Heating

e.g.
Activation Energy for
Multiple SHS

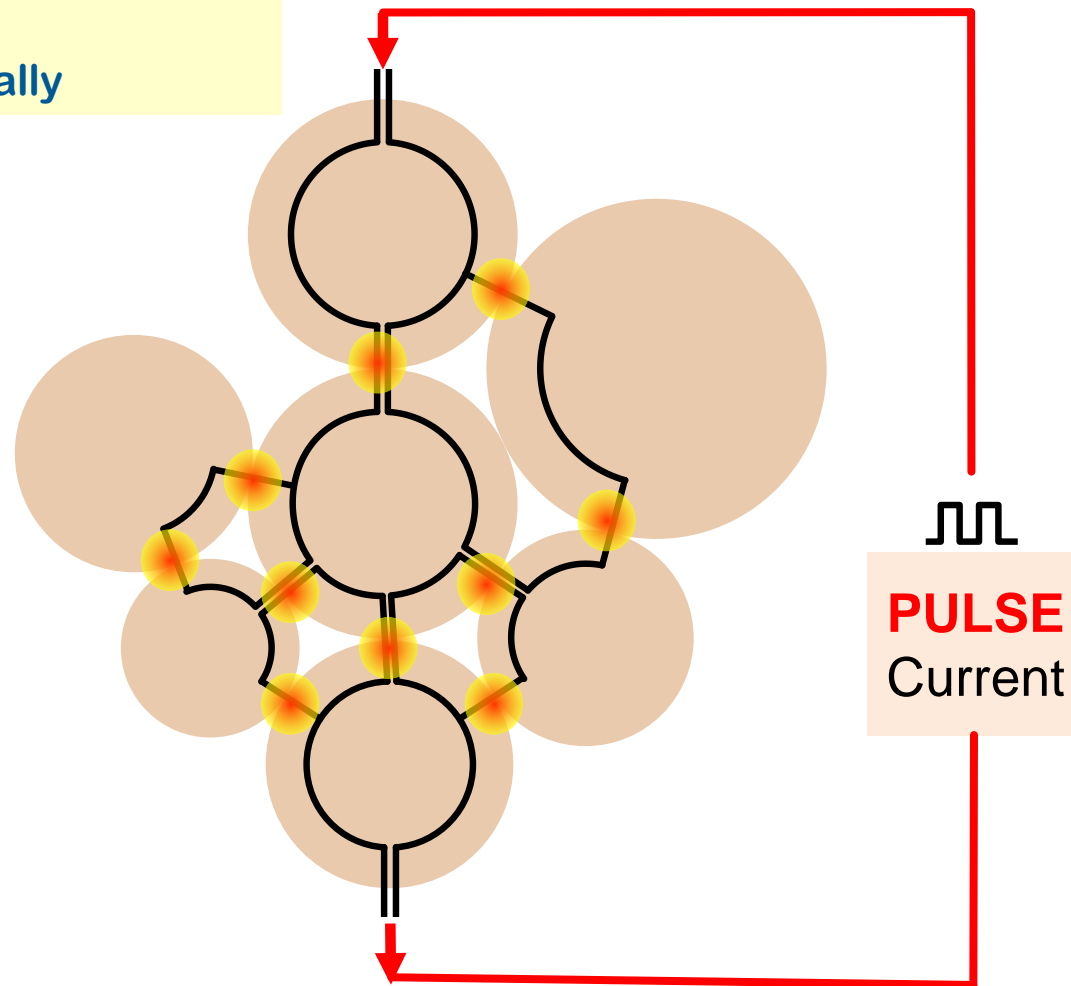


Potential Field Effects Assisting Sintering

POTENTIAL EFFECTS OF ELECTRICAL FIELD PROMOTING SINTERING:

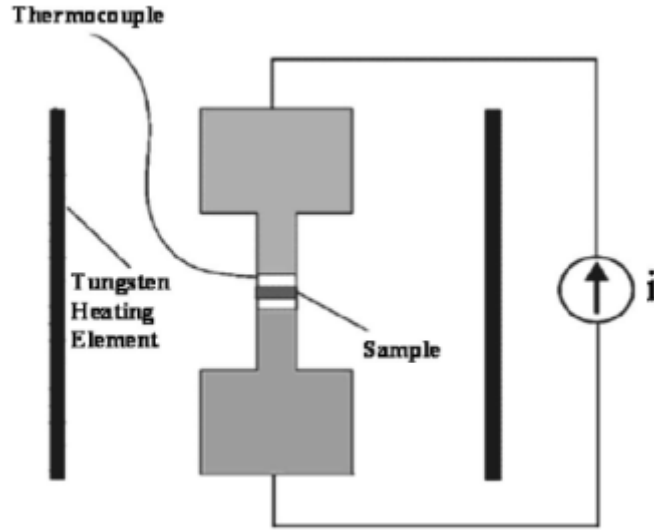
Boosted Locally, Peaked Temporally

- **Joule Heating**
- **Transport Phenomena**
 - Electrodiffusion
 - Electromigration
 - Generation of Dislocations
 - Thermoelectric Effects (Peltier)
- **Mechanical Force Effects**
 - Electrodynamic Forces
 - Electrostriction
 - Particle Alignment
 - Electroplasticity
 - Pinch Effect
 - Ponderomotive Forces
- **Surface Plasmons**
- **Multiple SHS** (selfpropagating HT synthesis)
- **Dielectric Phenomena**
 - Polarization
 - Dielectric Breakdown

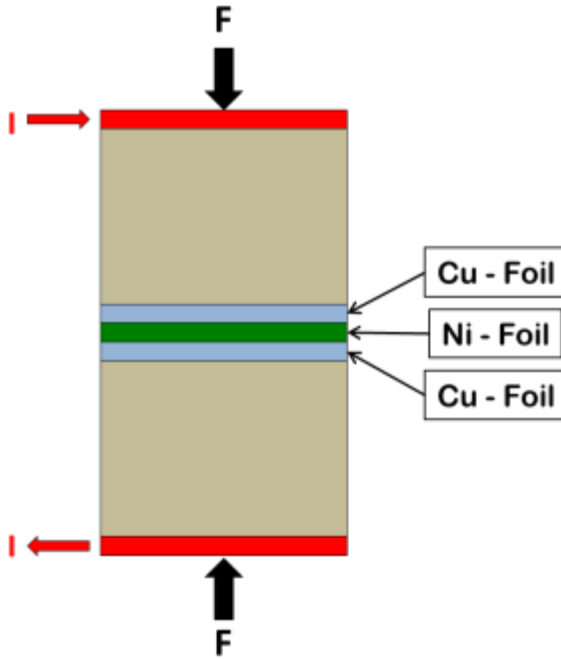


Diffusion Bonding of Cu / Ni

Experiment

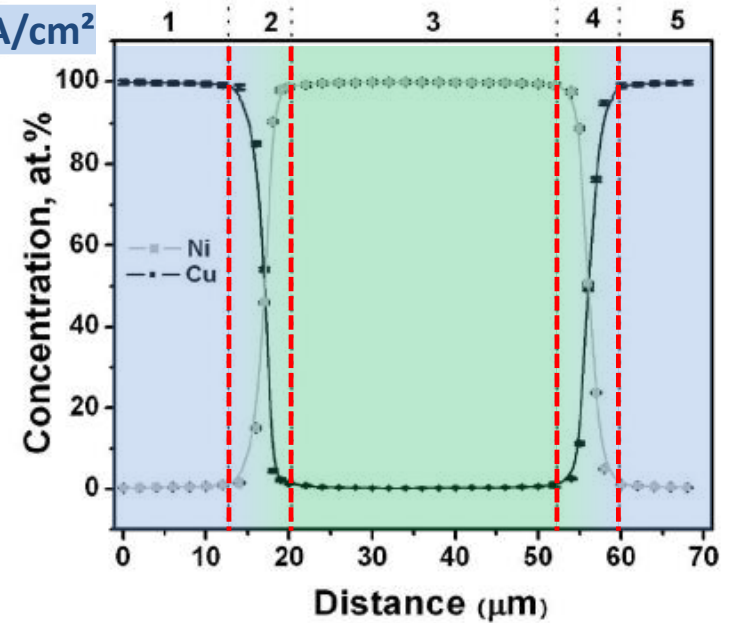


Sample

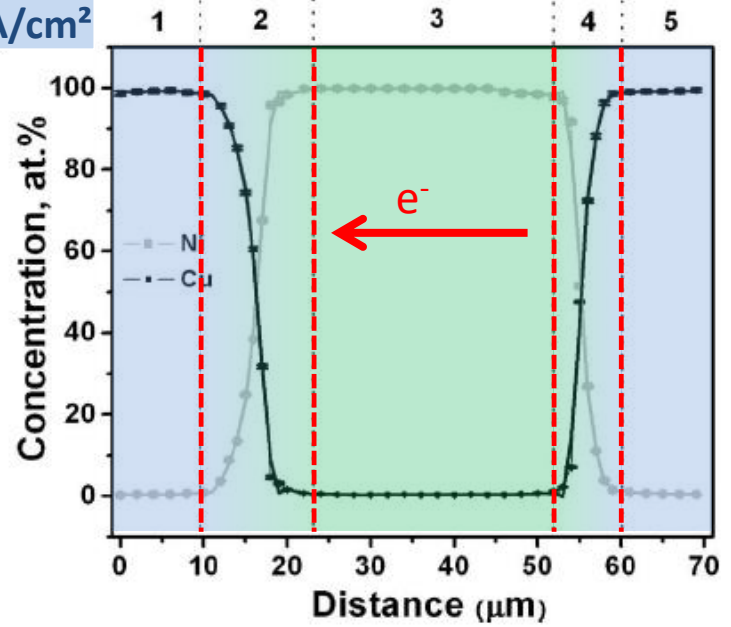


Result after 2h at 650°C

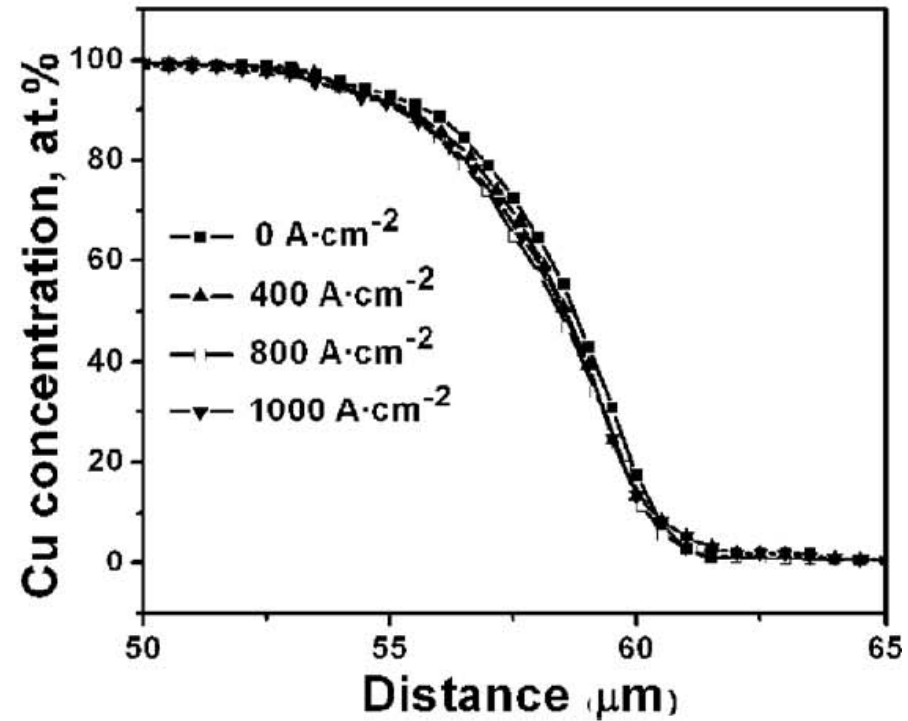
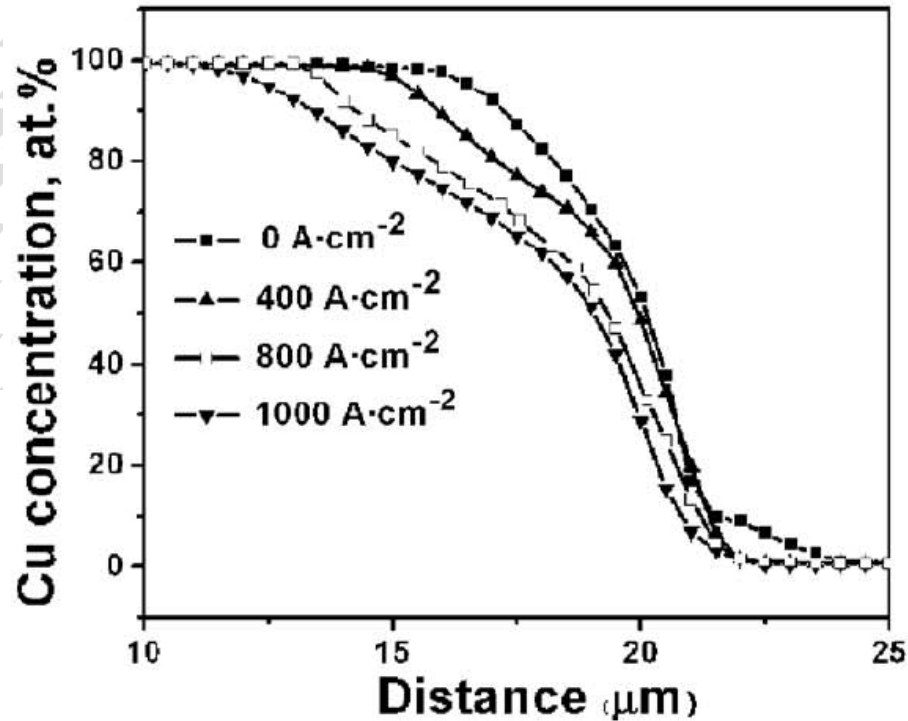
0 A/cm²



800 A/cm²



Diffusion Bonding of Cu / Ni



Direction of Electron Migration

Ni >> Cu

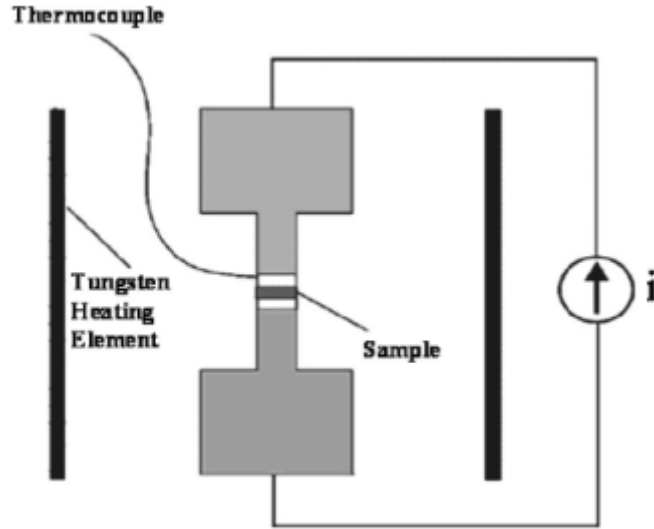
Cu >> Ni

Influence of Current Direction! = „Electromigration“

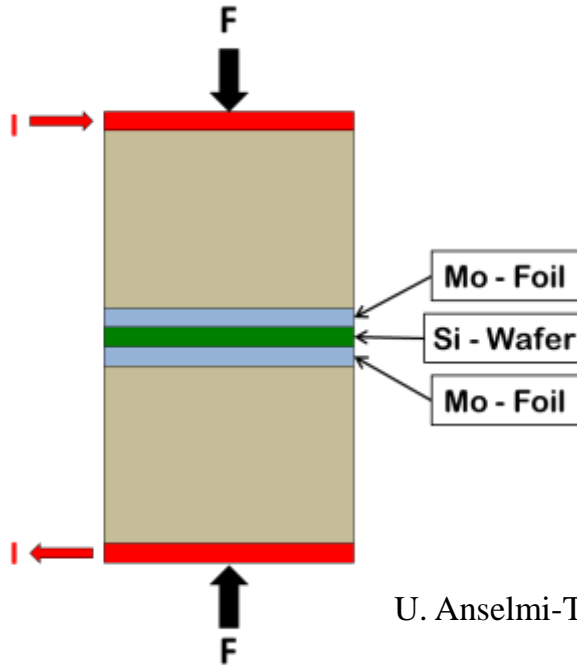


Intermetallic by Reaction Sintering of Mo / Si

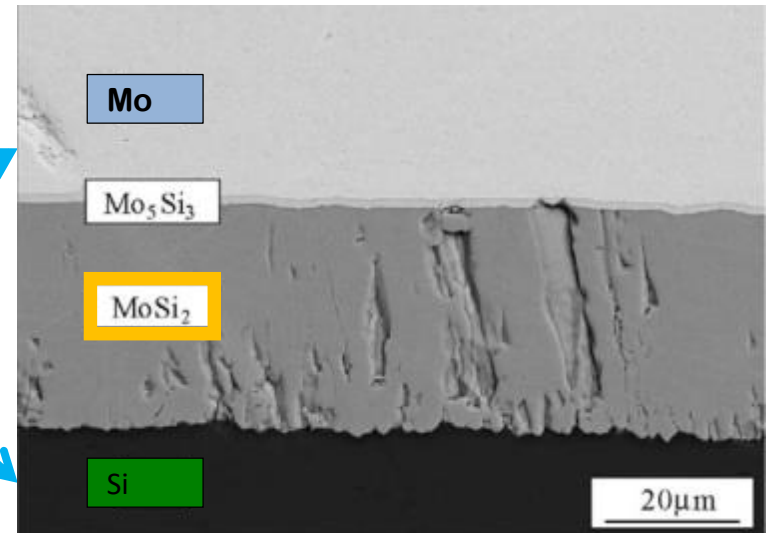
Experiment



Sample



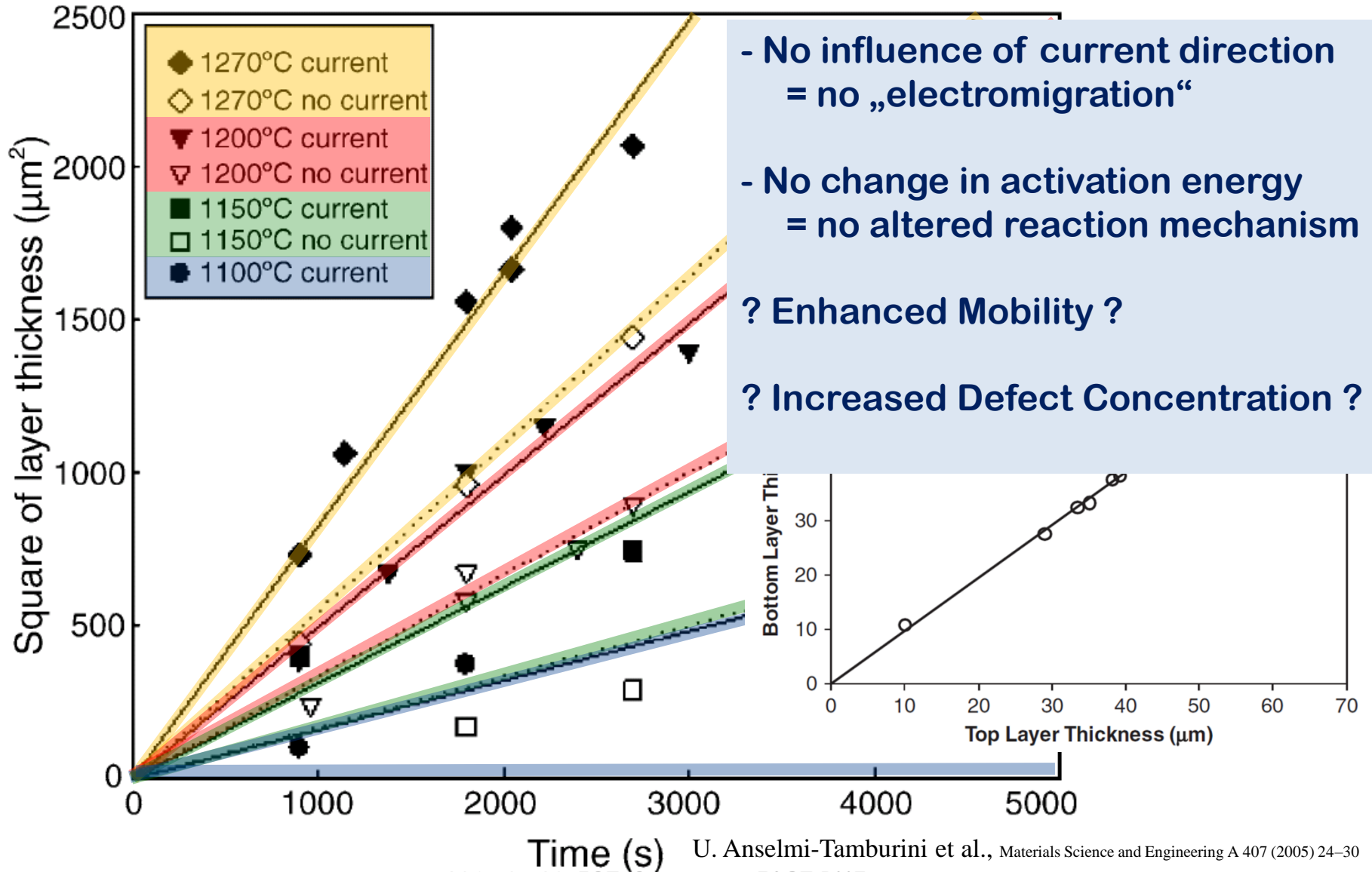
Result



U. Anselmi-Tamburini et al., Materials Science and Engineering A 407 (2005) 24–30

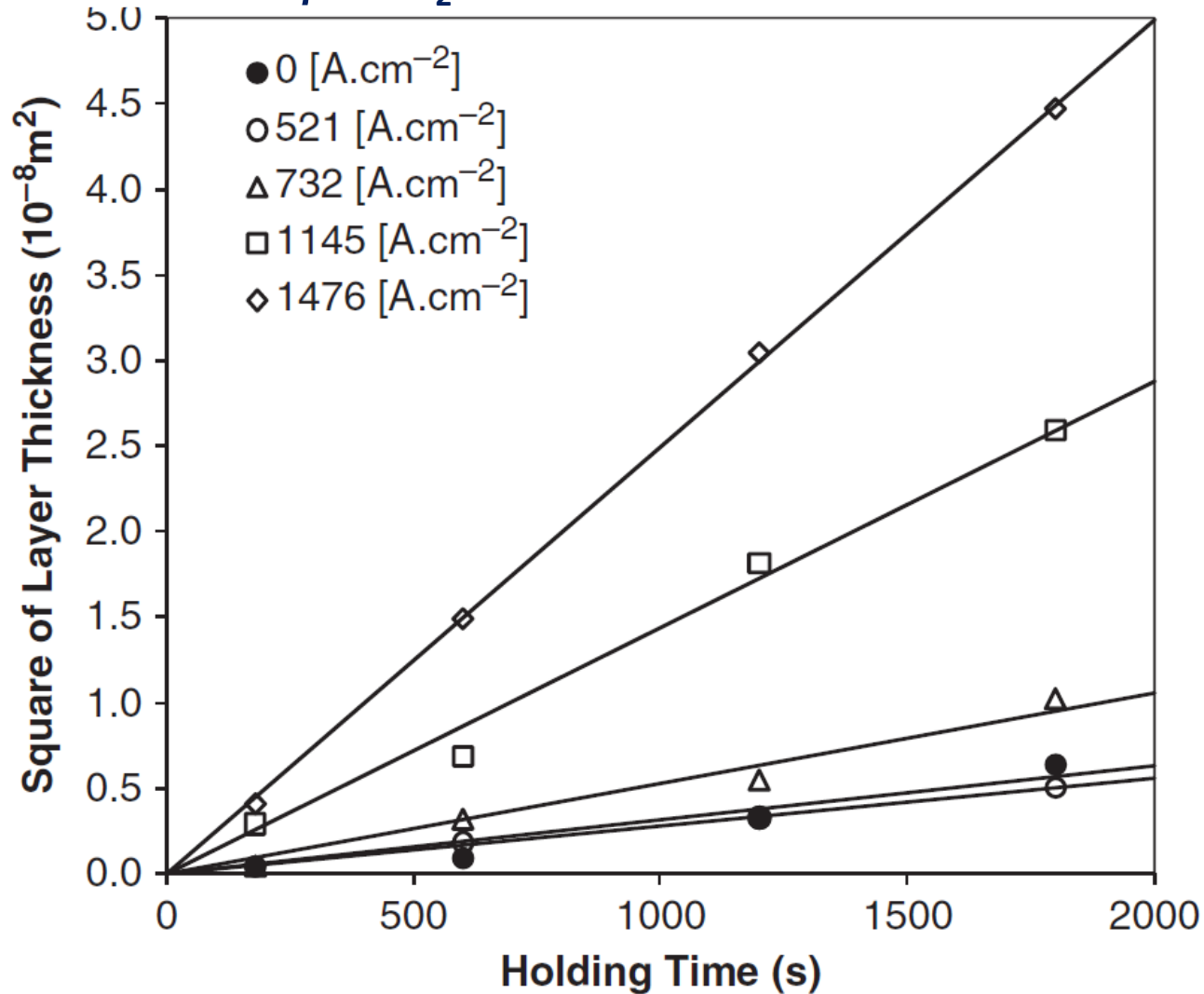
Intermetallic by Reaction Sintering of Mo / Si

MoSi₂ Formation



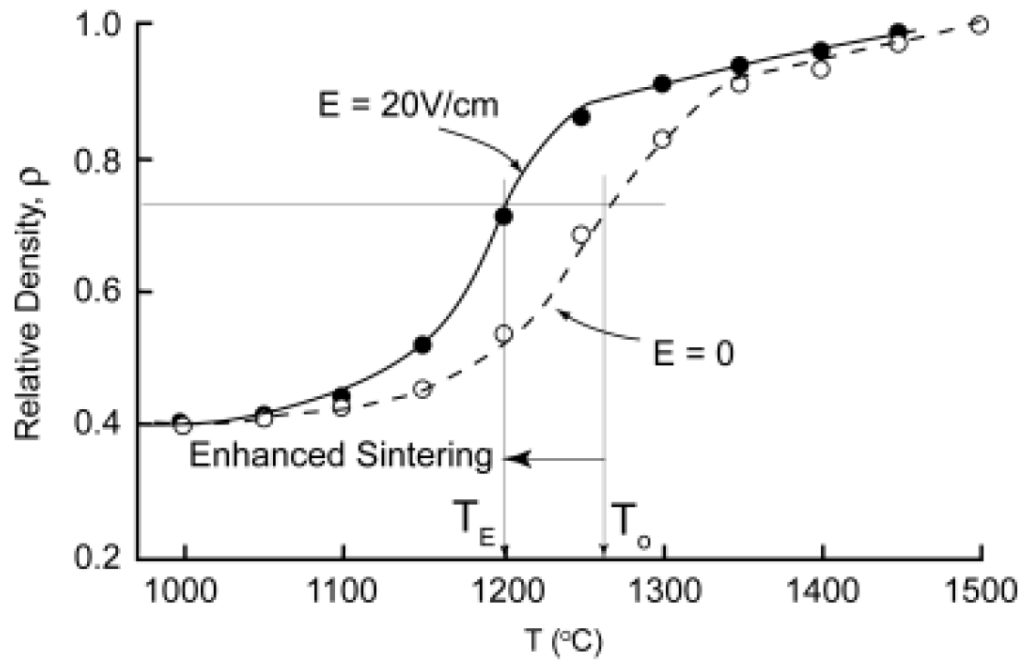
Reaction Sintering of Mo / C

β - Mo₂C Formation at 1570°C



Z.A.Munir et al., J.Am.Ceram.Soc. 94 (2011) 1-19

FAST/SPS of 3Y-TZP



J. Am. Ceram. Soc., ■ ■ ■ 1-3 (2010)
 DOI: 10.1111/j.1551-2916.2010.03905.x
 © 2010 The American Ceramic Society

Enhanced Sintering Rate of Zirconia (3Y-TZP) Through the Effect of a Weak dc Electric Field on Grain Growth

Di Yang,^{1,§} Rishi Raj,^{1,†} and Hans Conrad[§]

ELSEVIER

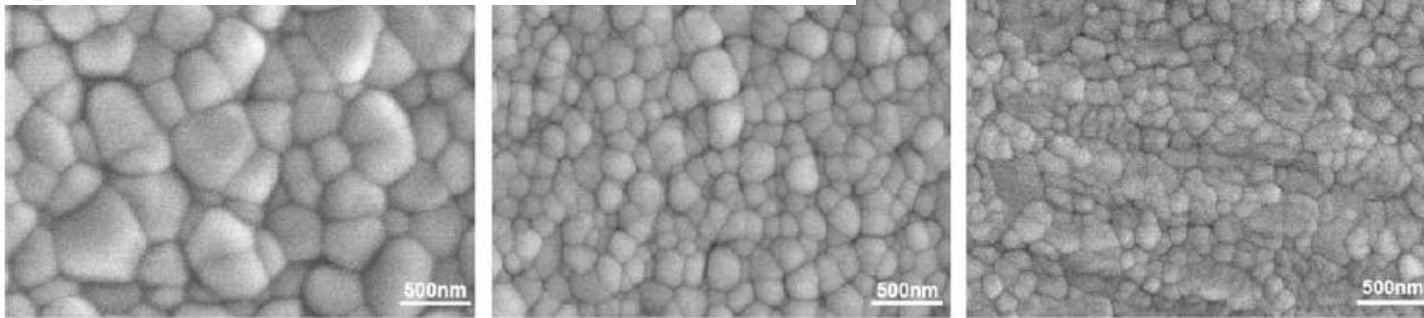
Scripta Materialia 63 (2010) 328–331

www.elsevier.com/locate/scriptamat

Enhanced sintering rate of zirconia (3Y-TZP) by application of a small AC electric field

Di Yang and Hans Conrad*

Fig. 3. The densification rate as a function of temperature in a constant heating rate experiment.



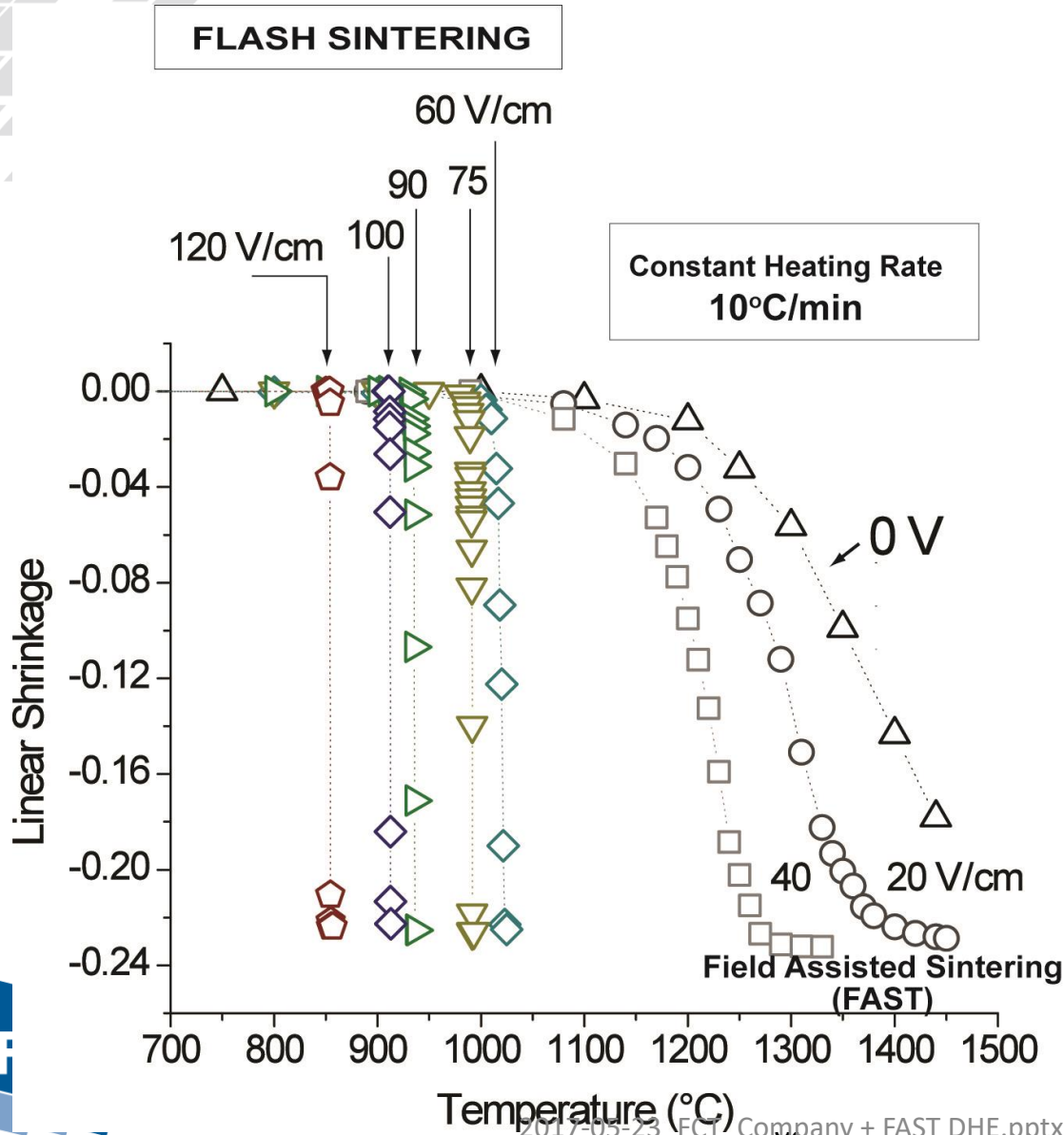
$E = 0$ ($d = 360\text{nm}$)

DC ($d = 217\text{nm}$)

AC(60Hz) ($d = 134\text{nm}$)

Figure 3. SEM micrographs showing the effect of a small DC and AC field ($E = 15\text{V/cm}$) on the grain size d of fully sintered ($\rho_r = 1.0$) 3Y-TZP.

FAST/SPS of 3Y-TZP



Influence of Externally Imposed and Internally Generated Electrical Fields on Grain Growth, Diffusional Creep, Sintering and Related Phenomena in Ceramics

Rishi Raj,[†] Marco Cologna, and John S. C. Francis

J. Am. Ceram. Soc., **94** [7] 1941–1965 (2011)

Advantages of FAST/SPS

Lower Sintering Temperature

and/or **Reduced Cycle Time**

Lower Pressing Forces

+ **Suppressed Grain Growth Enabling Nano-Materials**

+ **Reduction of Unwanted Chemical Reactions**

+ **Decreased Energy Consumption**

+ **Higher Productivity**

+ **Reduced Invest for Sintering Equipment**

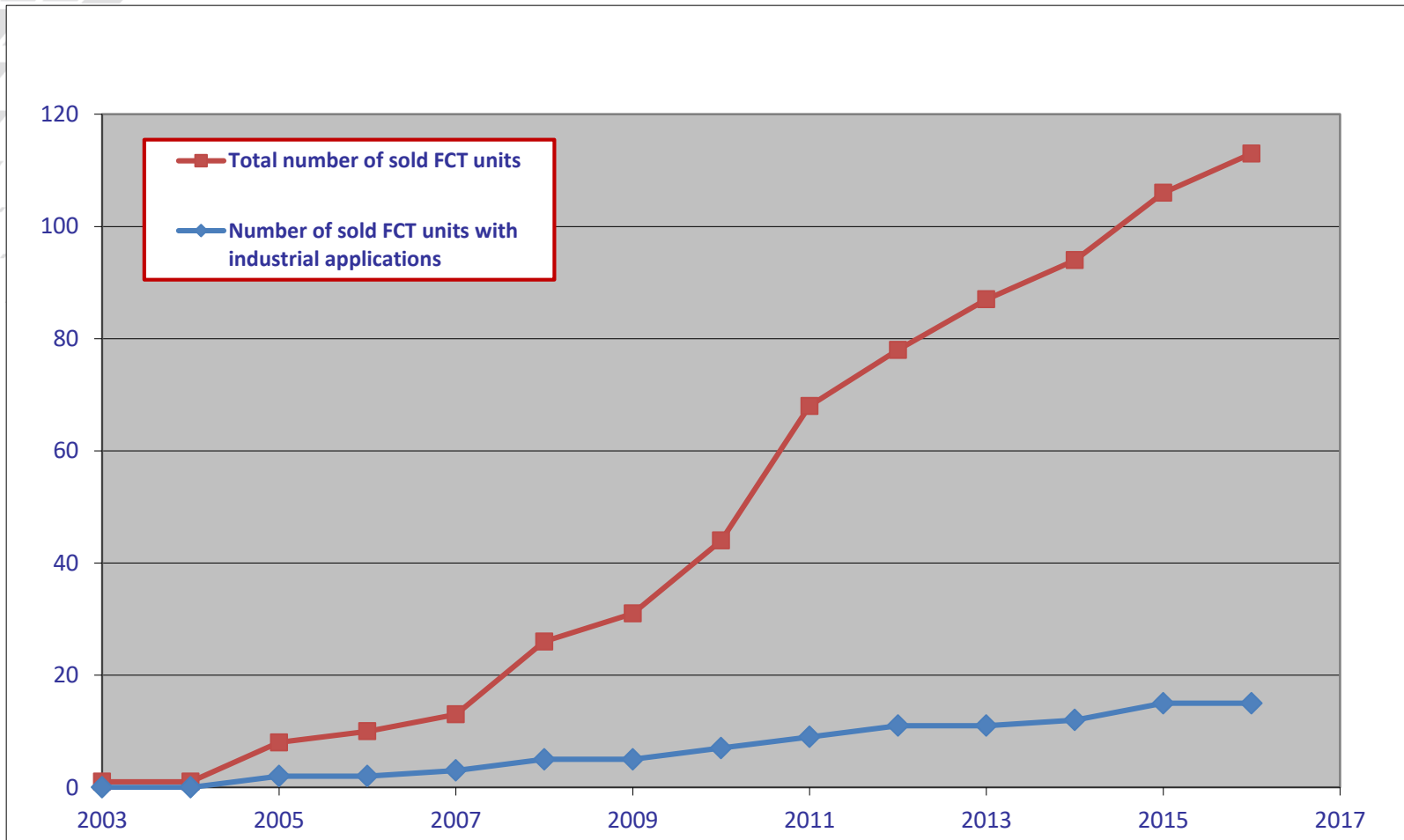
+ **Increased Lifetime of Pressing Tools**

Better Materials !

Better Efficiency !



FCT's FAST/SPS Systems Worldwide



“The Lab is the Classical Application Field of FAST”

Why?

Advantages of FAST/SPS:

- ▶ High heating and cooling rates with low thermal gradients
 - ⇒ Rapid densification
 - ⇒ Suppressed grain growth
 - ⇒ Low alloying in MMCs, FGMs, etc...
 - ⇒ New metastable materials and composites possible
- ▶ The material scientist can create 10...20 samples a day
- ▶ Each one made of an all new material



FAST/SPS System for the Lab - 100 kN



Technical Data

Pressing force	max. 100 kN
Temperature	RT – 2200°C
Sample size	∅ max 60 mm
Heating power	42 kW

Options:

- ▶ **Advanced Current Pulse Parameters**
- ▶ **Measurement of Electrical Resistivity**
- ▶ **Vacuum, Protection Gases**
- ▶ **Glove Box Integration**

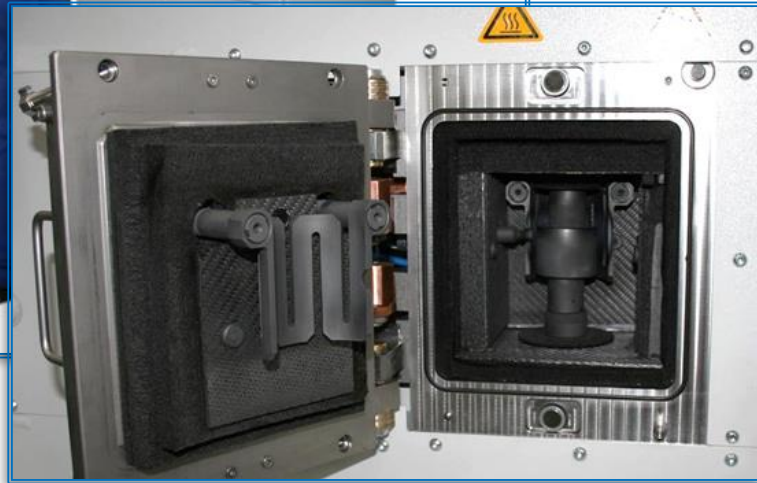


FAST/SPS System with Glove Box Option



- Sliding doors provide convenient operation of the glove box as well as direct access to the process chamber

Multi Purpose System for the Lab - 25 kN



Technical Data

Pressing force	max. 25 kN
Temperature	RT – 2200°C
Sample size	∅ max 30 mm
Heating power	FAST/SPS: 20 kW Hybrid: 10 kW
Flash Power	200 V 30 A

Operating Modes: *(combinable in any order)*

- ▶ **FAST/SPS**
- ▶ **Hot Pressing**
- ▶ **FAST/Hybrid** *(minimized thermal gradients)*
- ▶ **FAST/Flash** *(high field hybrid)*

Options:

- ▶ **Automatic Mode Switching**
- ▶ **Advanced Current Pulse Parameters**
- ▶ **Measurement of Electrical Resistivity**
- ▶ **Vacuum, Protection Gases, Hydrogen, Air**

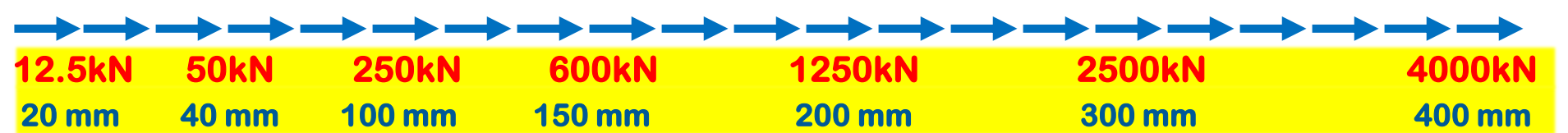


Range of FAST/SPS Units from Lab Scale to Industrial Scale



Lab Scale FAST

Industrial Scale FAST



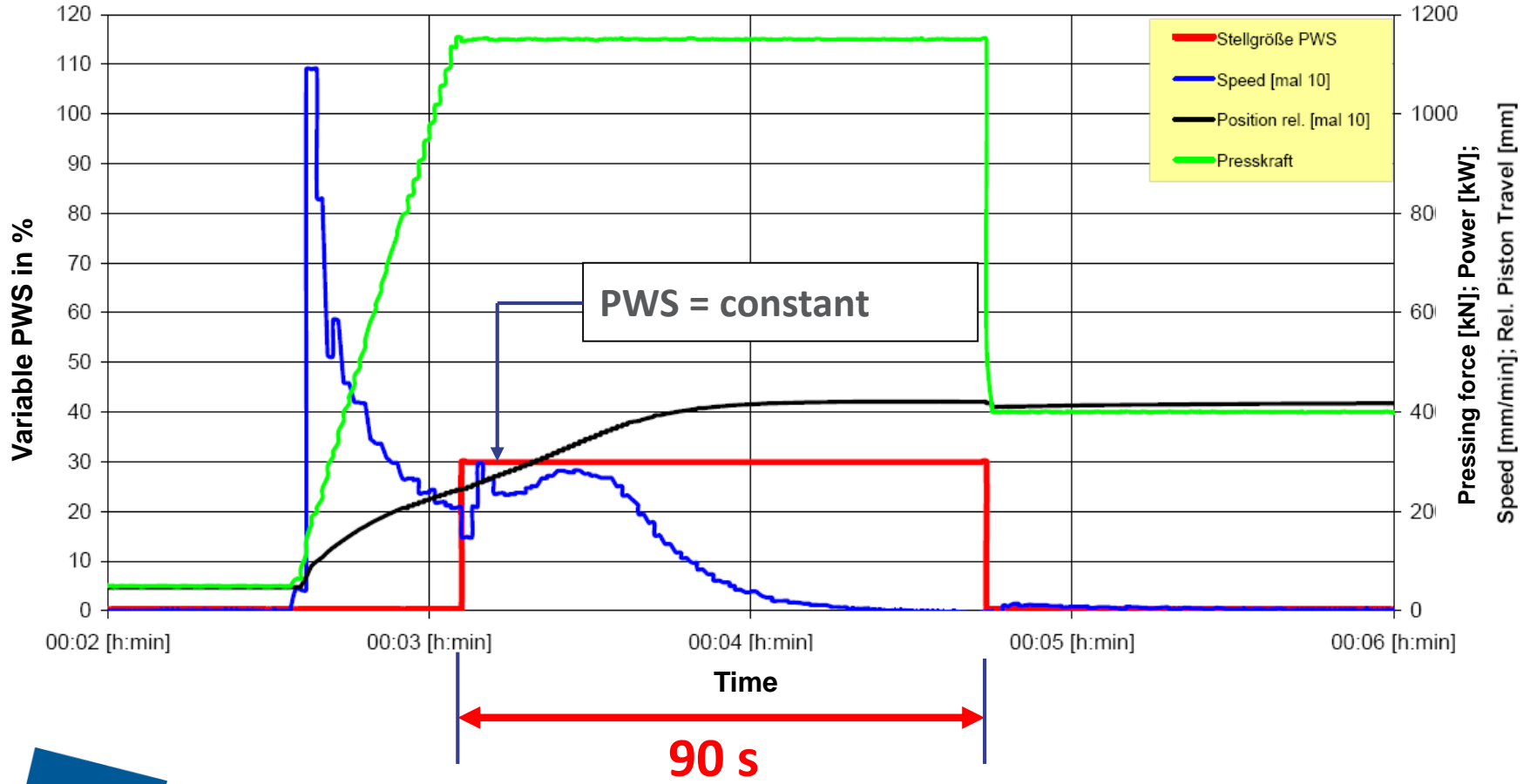
FAST / SPS of Forging / Extrusion Blanks Nano-Scaled Al / Si / ... Alloy or AMC



Th. Schubert, J. Schmidt, T. Weissgärber, B. Kieback, Spark Plasma Sintering and Hot Extrusion of Aluminium Alloy Powder
Proceedings of the EuroPM 2009, Copenhagen, 2009, Vol. 2, 363-368

SPS Process of Al/Si/... Alloys

Pre-Shaped Blank for Piston Forging
Full Density after 90 Seconds Heating Time



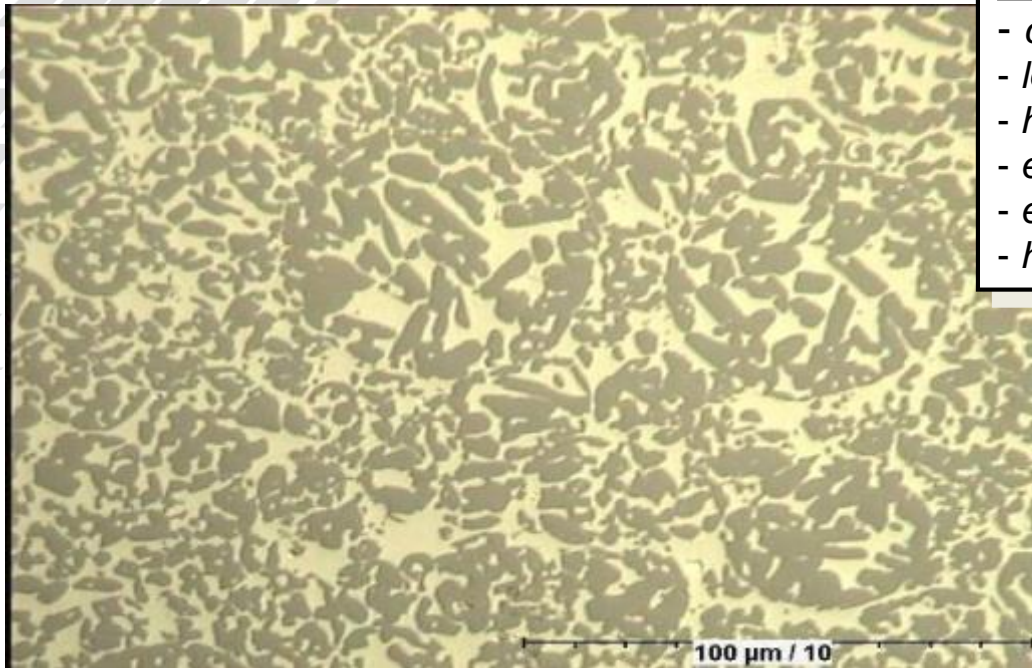
FAST / SPS Consolidated Al based MMC

Properties:

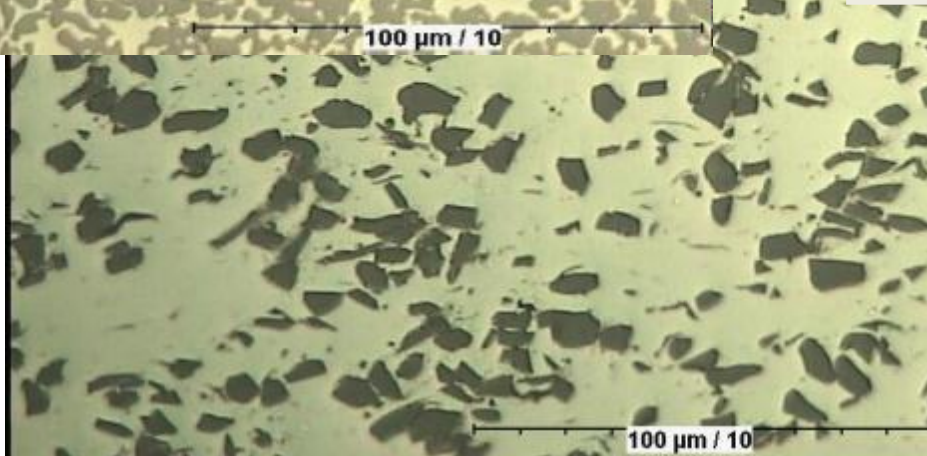
- controlled thermal expansion: 7 – 24 ppm
- low densities: 2,4 – 2,7g/cm³
- high thermal conductivity: 120 – 180 W/mK
- electrical conductivity: < 10⁻⁶ ohm x cm
- excellent thermal stability up to 500°C
- high specific stiffness

Replacements for:

- Copper Molybdenum (Cu-Mo / Mo-Cu)
- Copper Tungsten (Cu-W / W-Cu)
- Aluminium Silicon Carbide (Al-SiC)
- Kovar



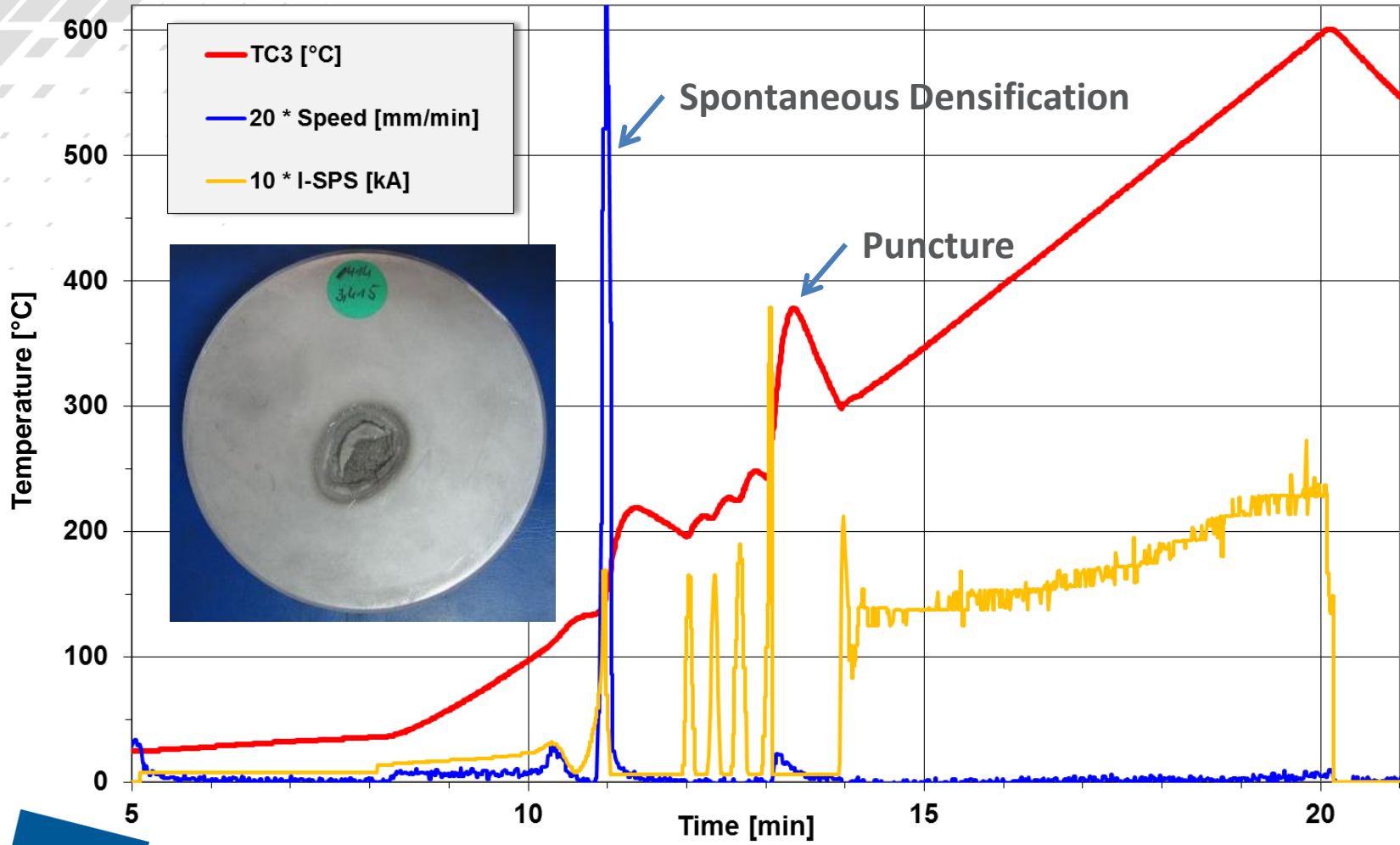
PM-SiAl40



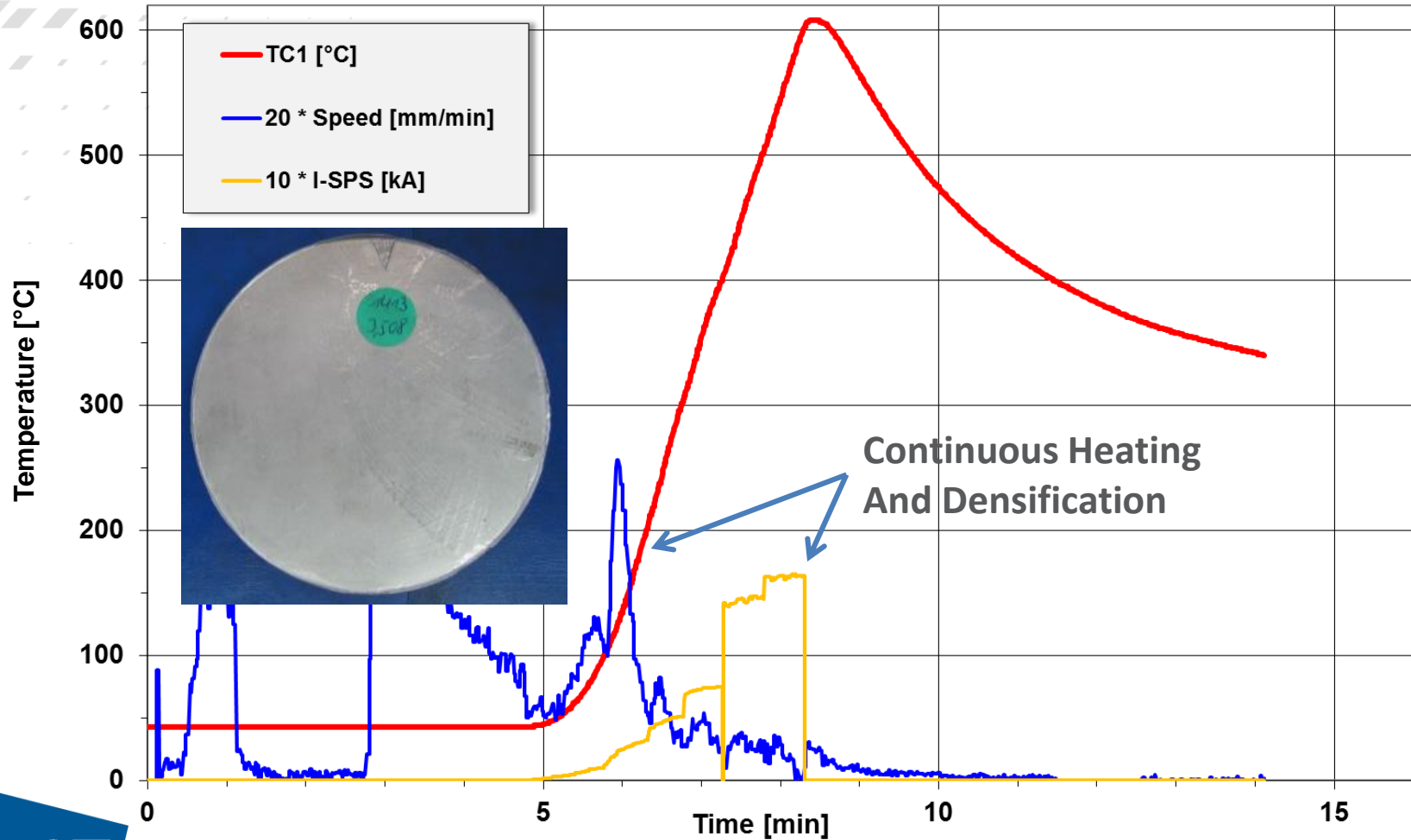
MMC – Al/B₄C 20%



Puncture of a Dia107mm Ti-Al-Disc by Disruptive Discharge of DC Heating Current

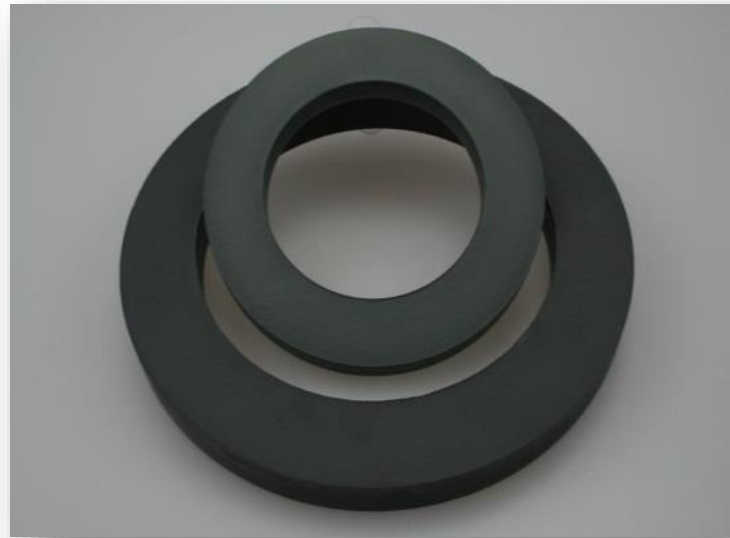


Rapid and Homogeneous Sintering of a Dia 107 mm Ti-Al-Disc by Pulsed DC Heating Current



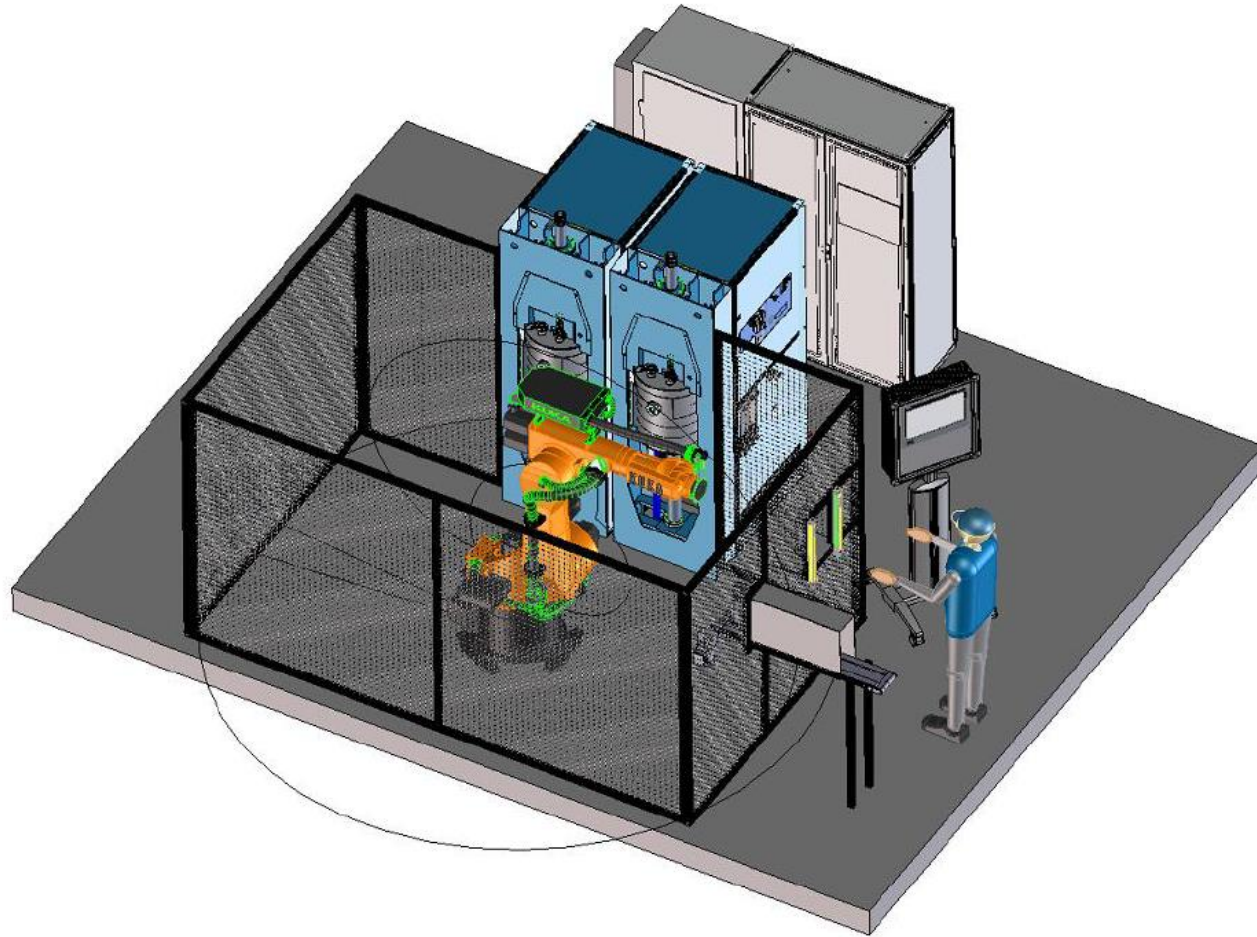
Applications for Near Net Shaped Components

Mouldings made of Si_3N_4 , SiC and B_4C



Wear rings made of Si_3N_4 and SiC with up to $\text{Ø}350$ mm (turbo gas compressors and circulation pumps in chemical industry)

Improved Productivity: Automation



Improved Productivity: Integrated Pressing Tool

FAST² - FAST/SPS Technology for LARGE Quantities

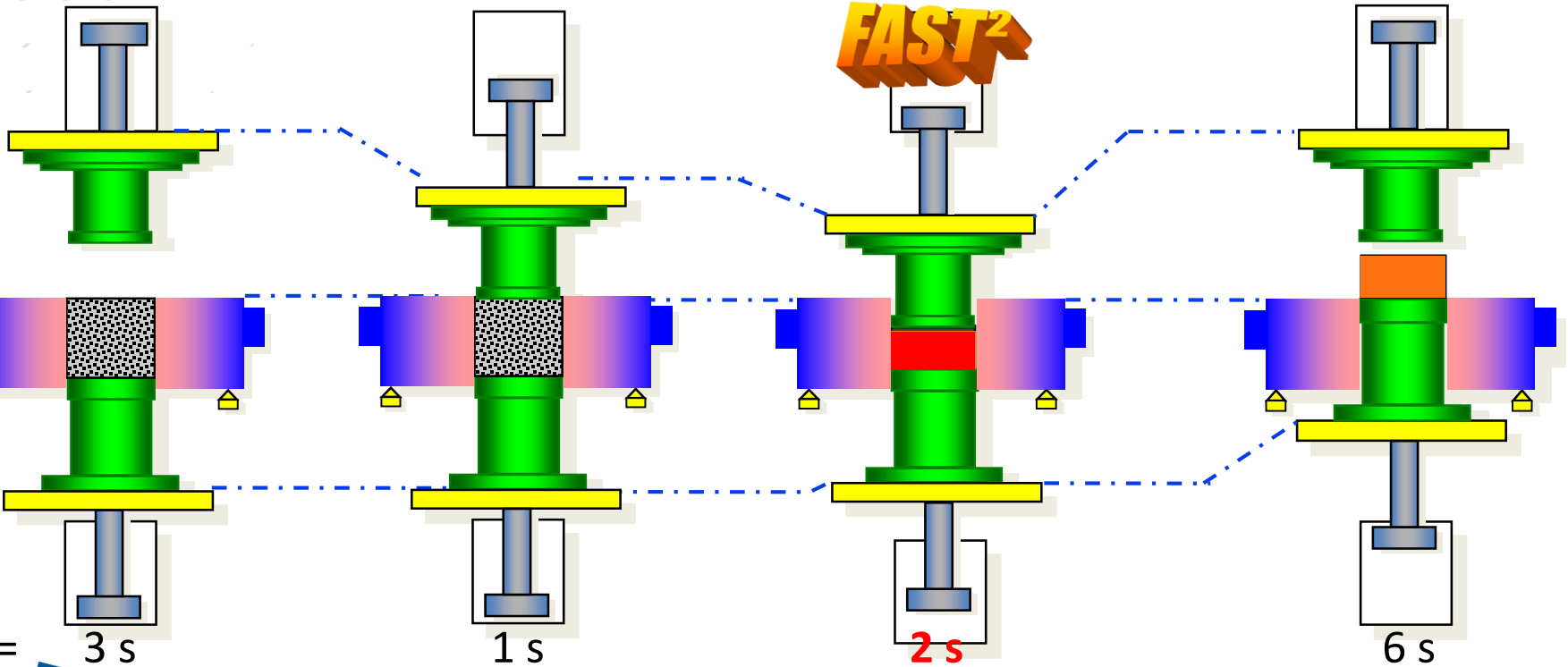
Fully Automatic Powder Press Producing Parts,
which are Net Shaped and Readily Sintered

Filling

Covering

Pressing/Dwell

Cooling/Ejecting



Improved Productivity: Integrated Pressing Tool

FAST² Prototype

**Double-Action Hydraulic Powder Press
With Integrated FAST² Sintering Technology:**

Pressing Force: 100 kN

Withdrawal Force: 56 kN

Pressing Travel (lower punch): 100 mm
(upper punch): 150 mm

Hydr. Center Pin Travel: 100 mm

Precision of Pressing Force: ± 0.7 kN

Stroke Rate max: 8 min⁻¹

Automatic filling system

- controlled by displacement transducer
- optional rocking motion

Electrical Power: 15 kW + 40 kW

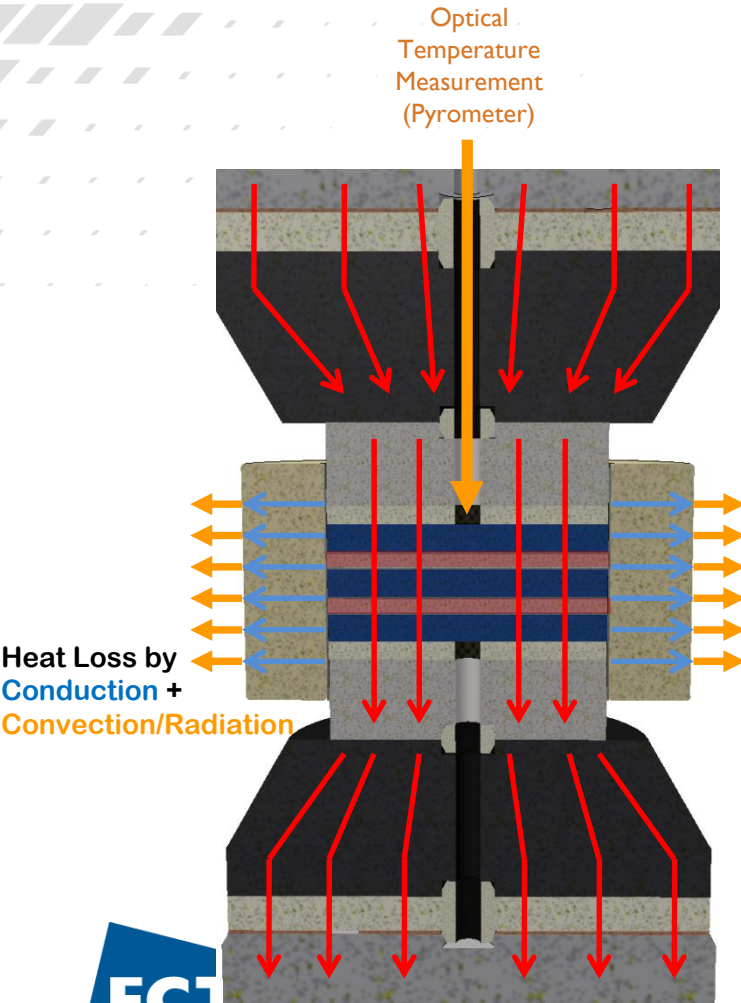
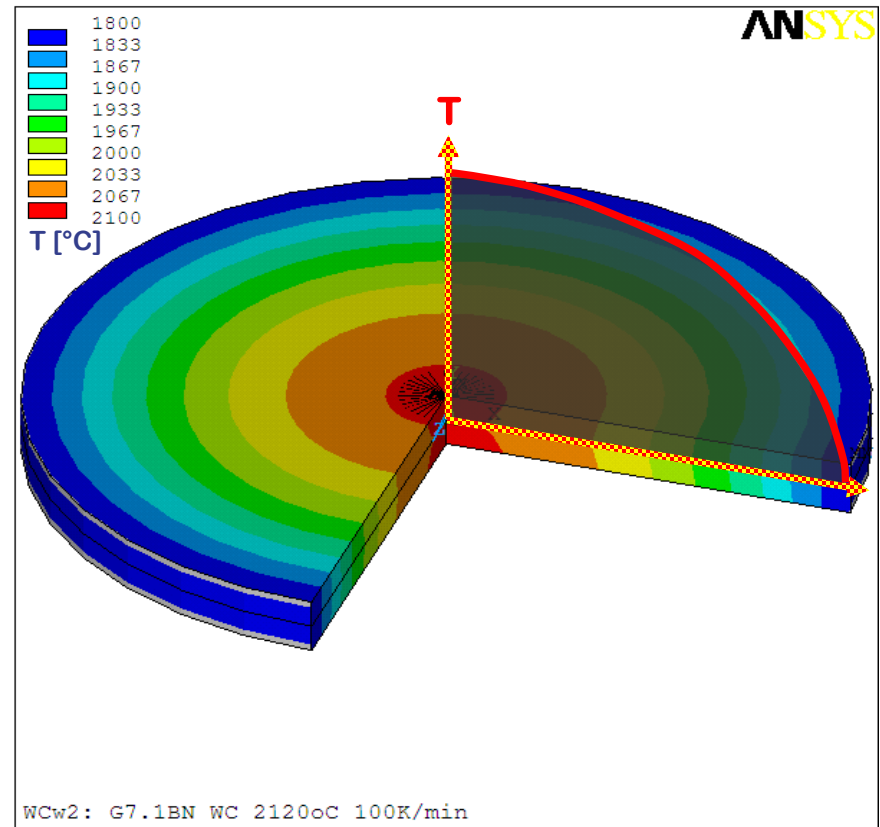


Improved Productivity: Further Increase of Heating Rate

STANDARD FAST/SPS

CHALLENGE:

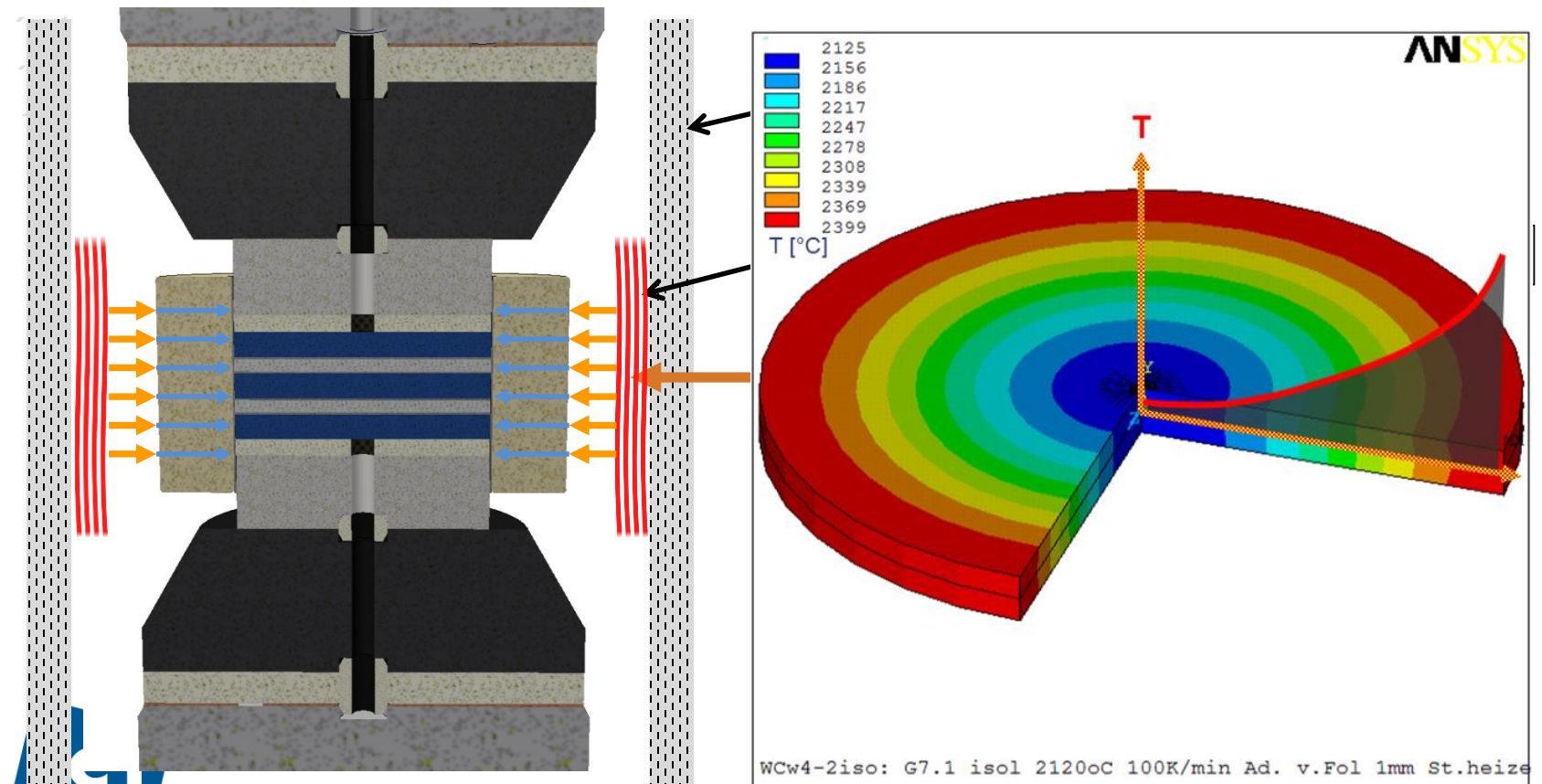
Thermal Gradients are Growing if Heating Rate, Temperature and Sample Size are Increasing!



Improved Productivity: Further Increase of Heating Rate

CONVENTIONAL HOT PRESSING

Direction of Thermal Gradients
Reverse to FAST/SPS Gradients



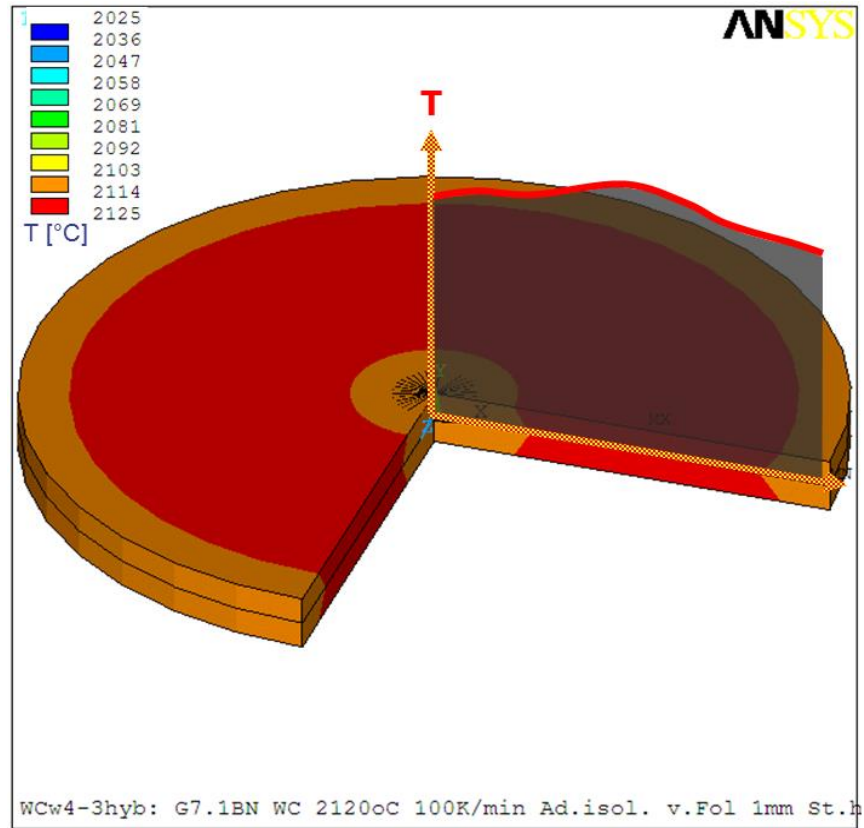
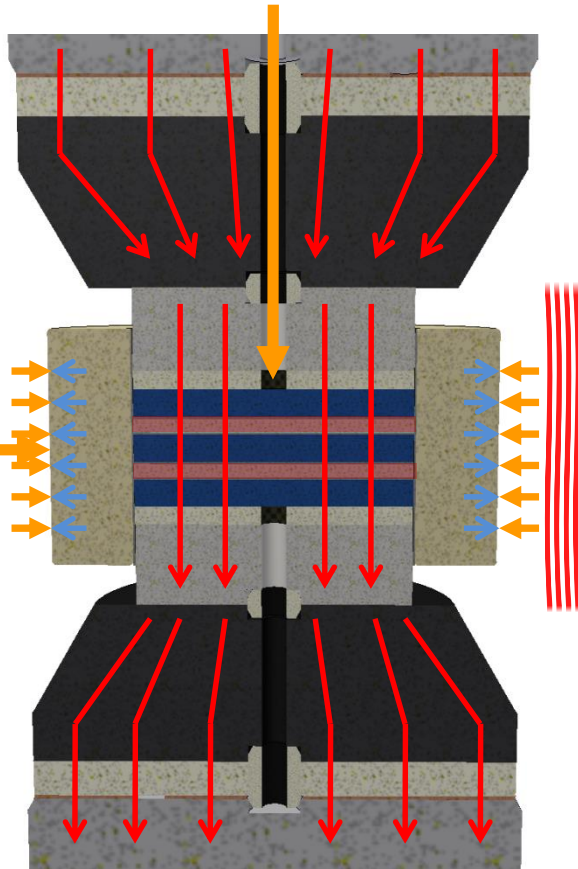
Improved Productivity: Further Increase of Heating Rate

FAST/Hybrid HEATING

Combination of Two Independently Controlled Heaters Allows Compensation of Thermal Gradients

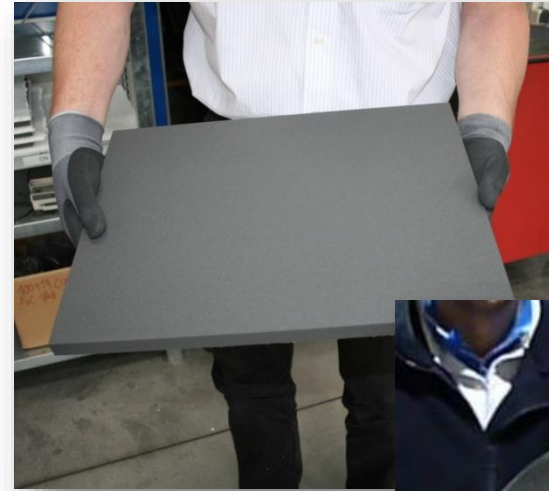
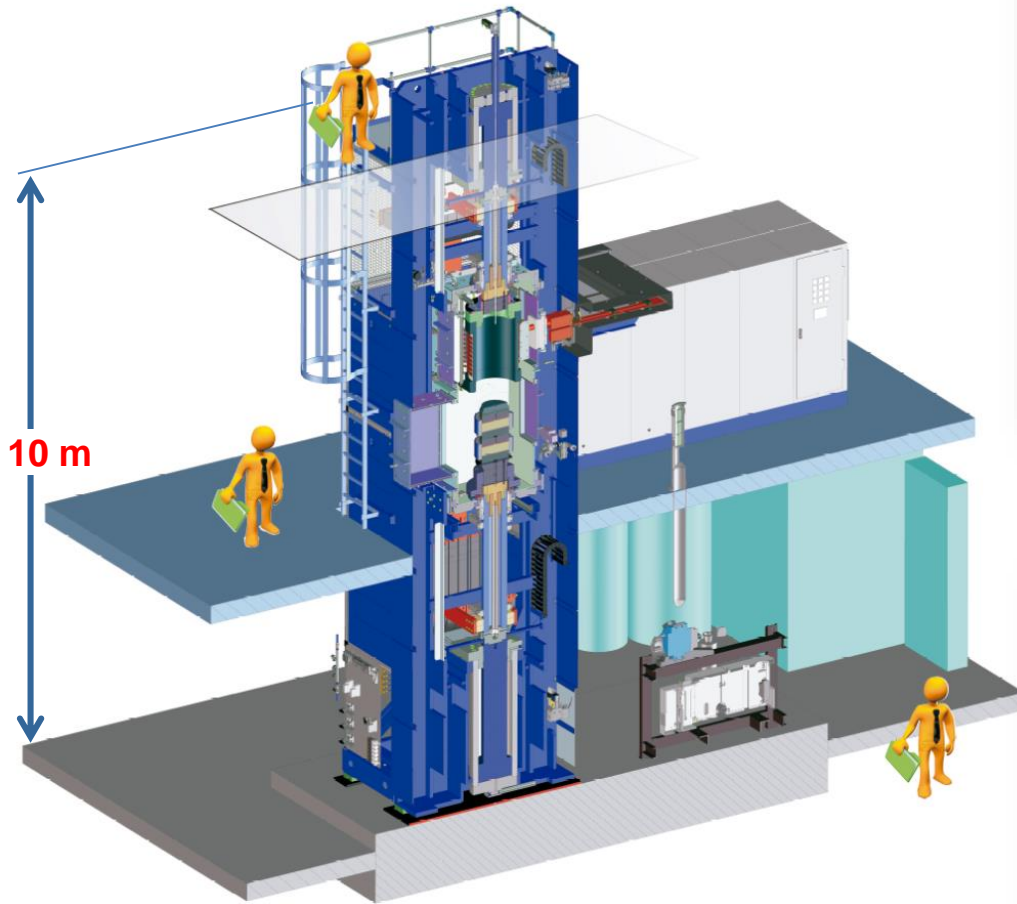
Optical
Temperature
Measurement
(Pyrometer)

Pyro-
meter



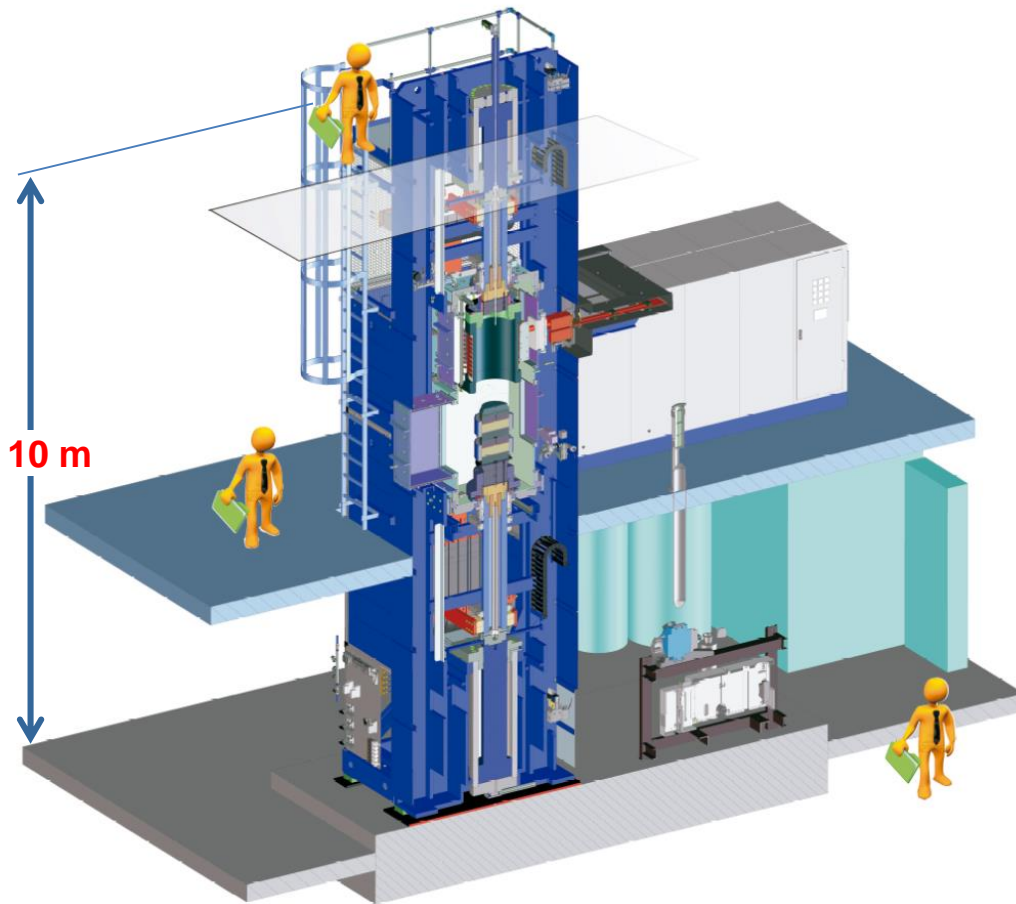
Improved Productivity: Large Parts

Industrial FAST/Hybrid System



Improved Productivity: Large Parts

Industrial FAST/Hybrid System



PERFORMANCE:

Pressing force	max. 4000 kN
Temperature	RT – 2400°C
Sample size	Ø150 – 450 mm
Heating power	FAST/SPS: 500 kW Induction: 500 kW
Gas pressure	ABS: $< 5 \cdot 10^{-2}$ mbar REL: up to 60 mbar
Working gases	Ar/N ₂ /Other



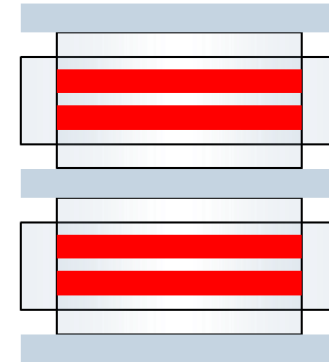
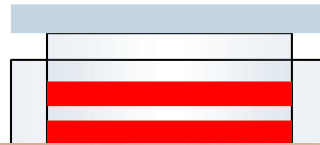
Improved Productivity: Multiple Tools

$n \times 1$

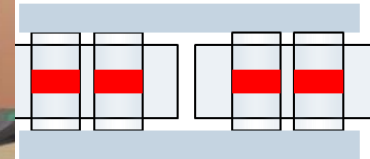
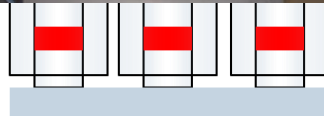
$1 \times m$

$n \times m$

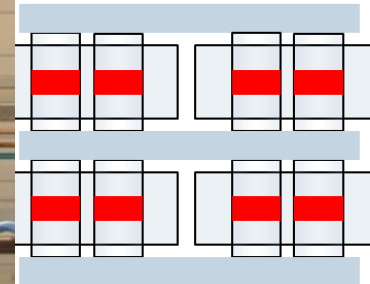
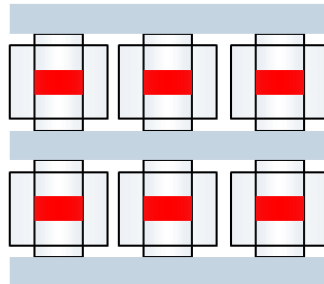
Serial



Parallel



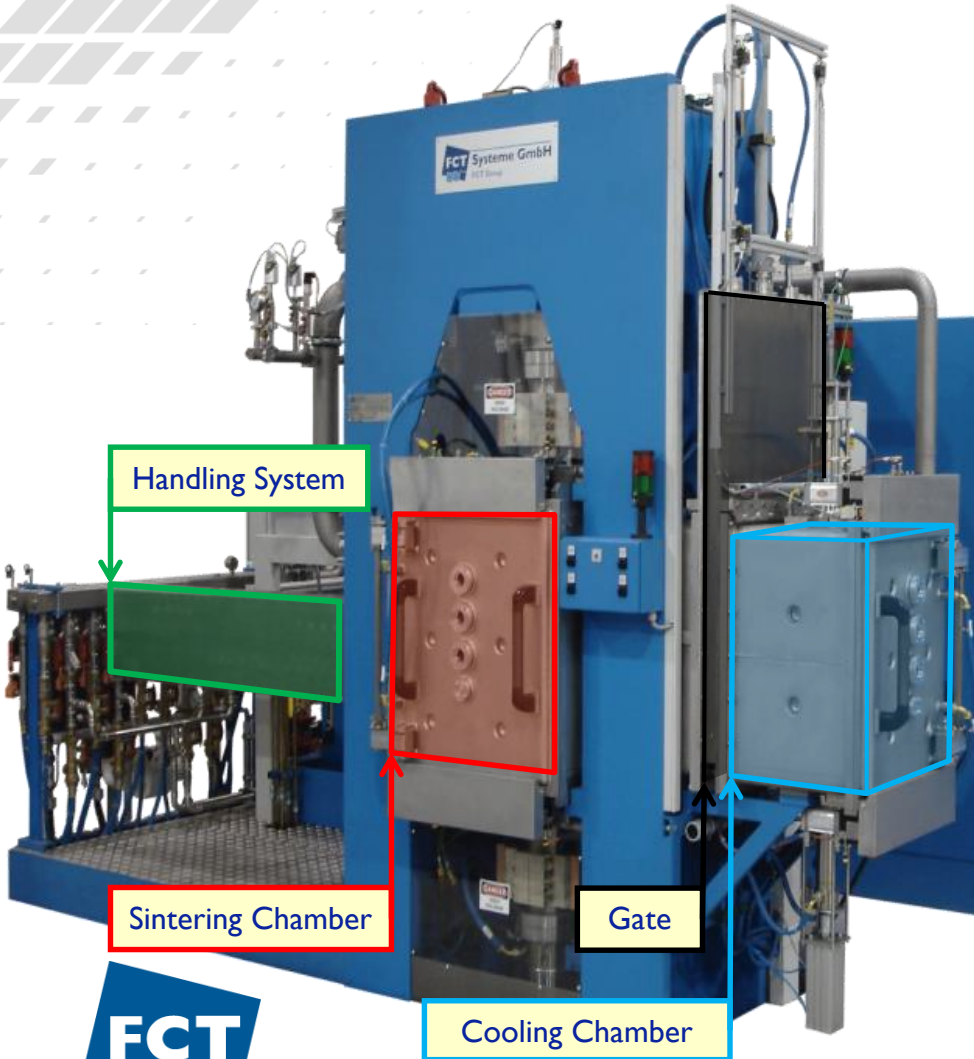
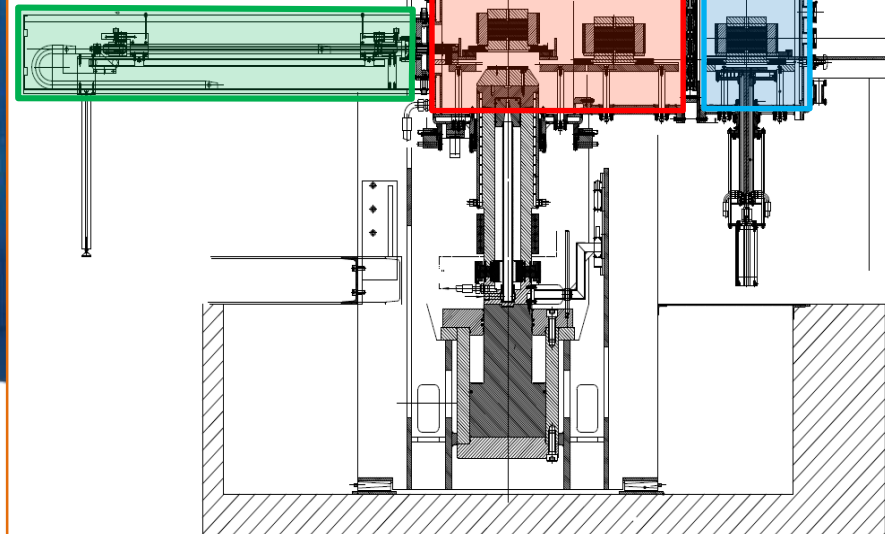
Serial -
Parallel



Improved Productivity: Decoupling of Process Steps

Double Chamber: Decoupling of **Sintering** Step and **Cooling** Step

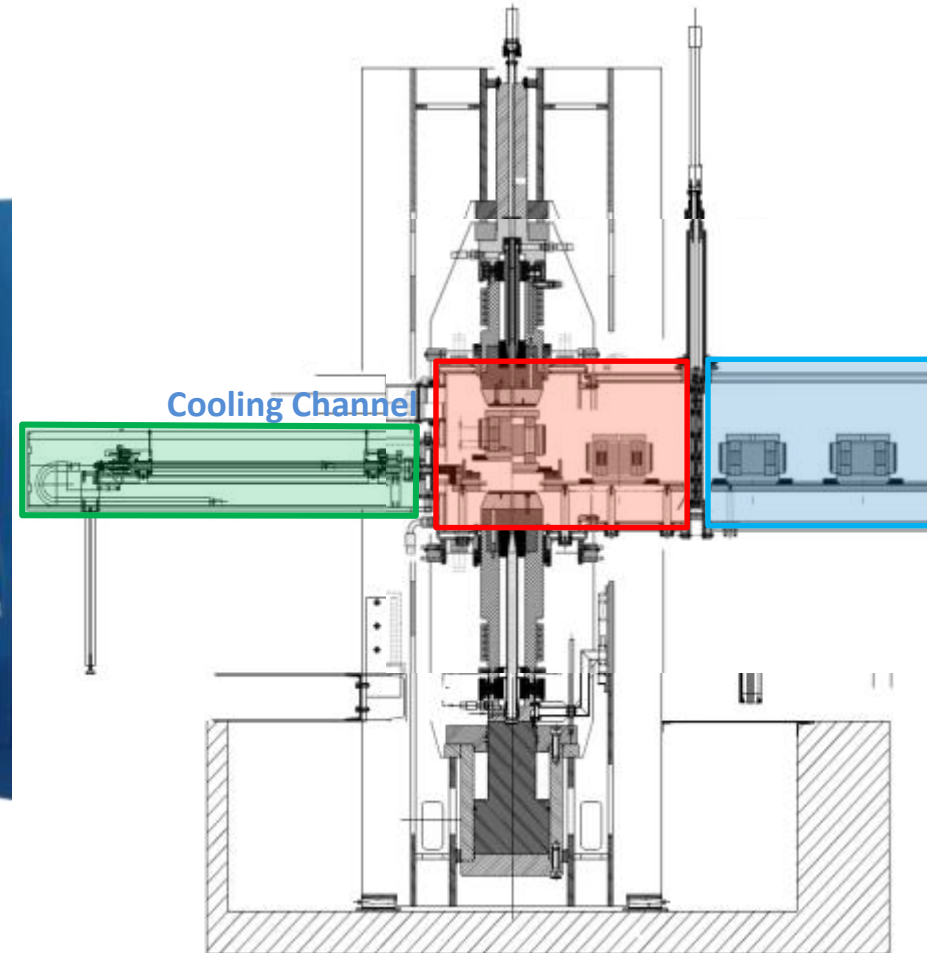
*Fast or Slow
Cooling Process*



Improved Productivity: Decoupling of Process Steps

FAST Production Unit
with Cooling Channel

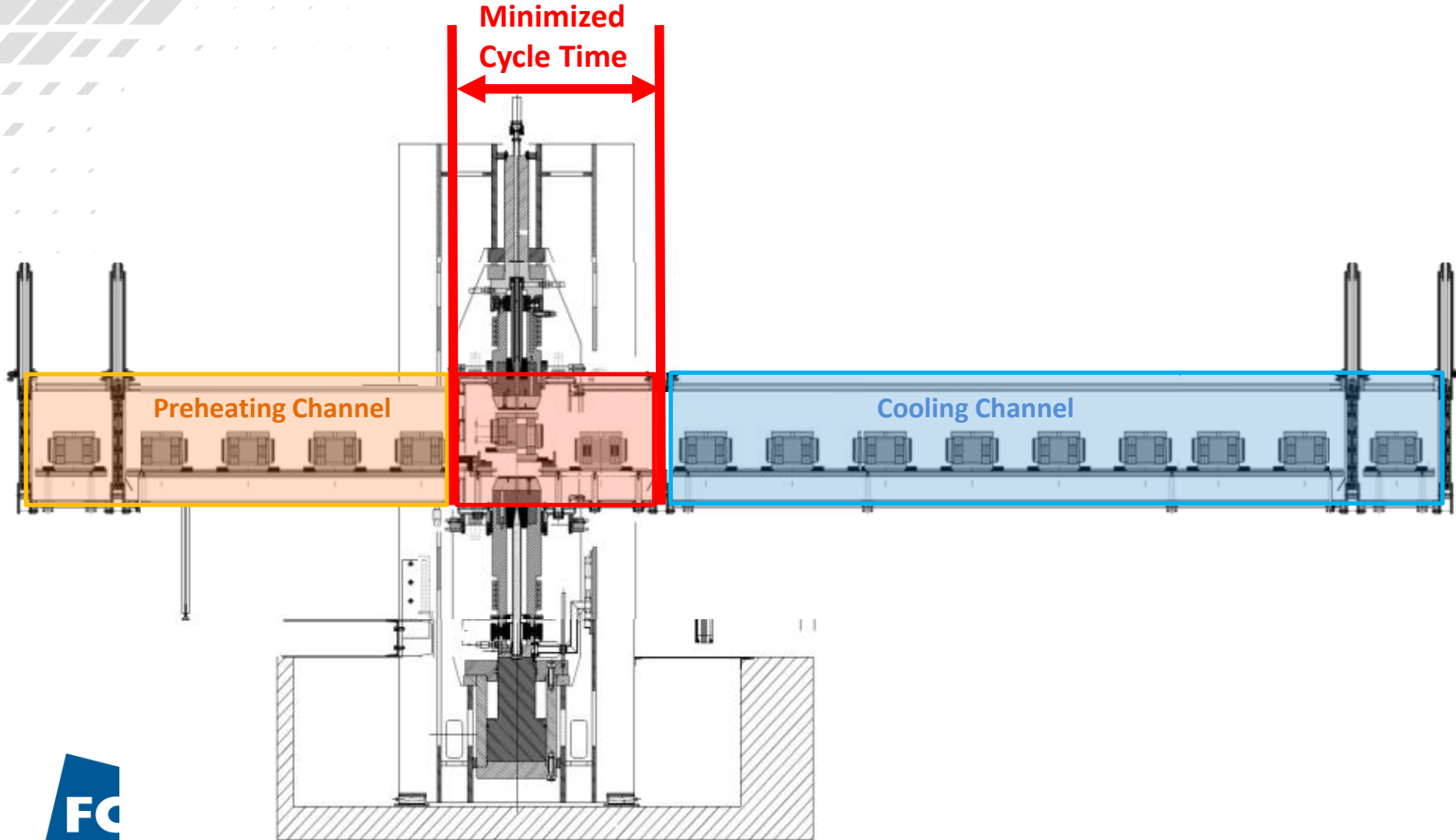
Double Chamber: Decoupling
of **Sintering** Step and **Cooling** Step



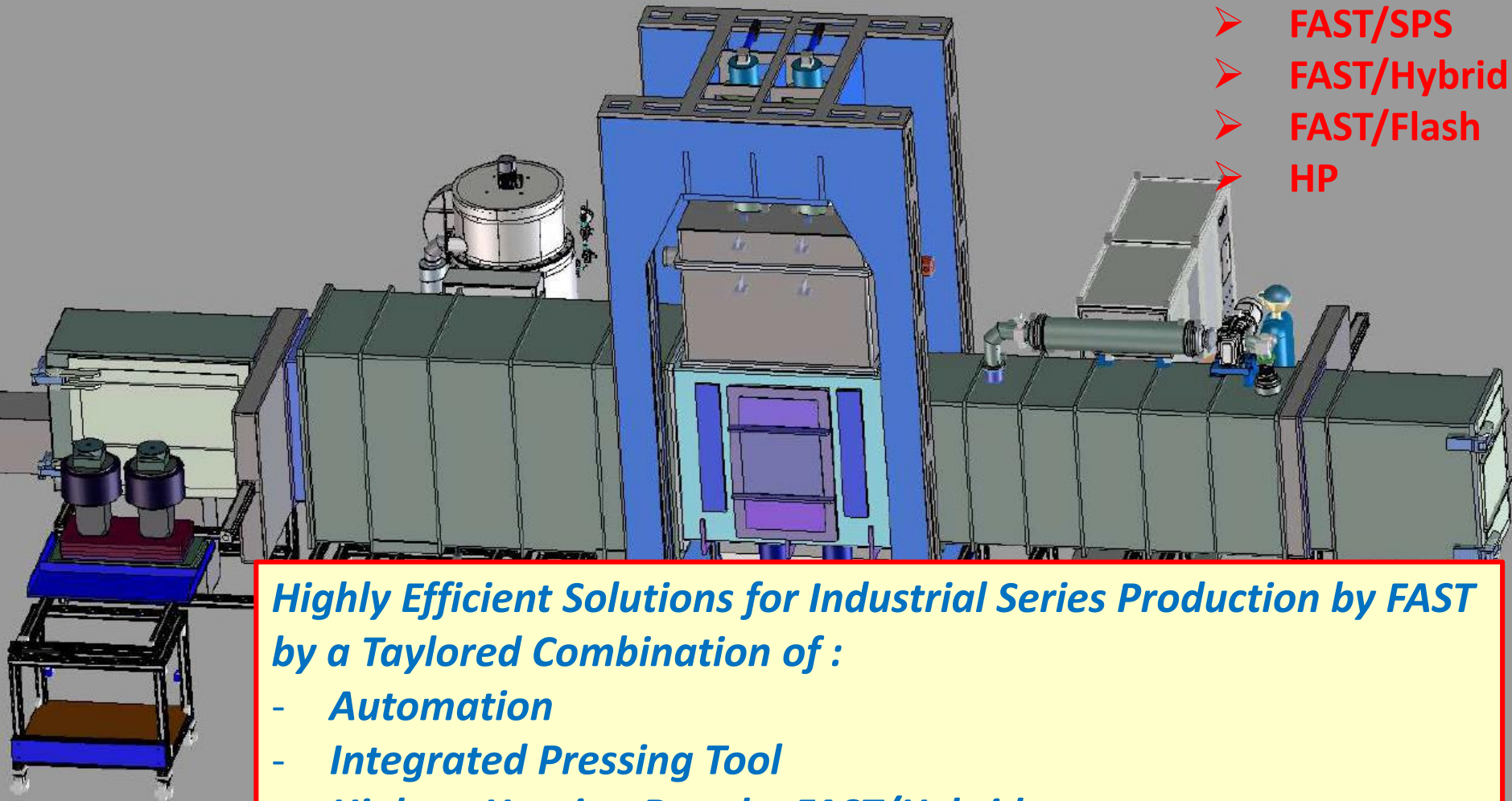
Improved Productivity: Decoupling of Process Steps

FAST Production Unit

with Preheating and Cooling Channel



FAST Production Unit with Preheating and Cooling Channel



Highly Efficient Solutions for Industrial Series Production by FAST by a Tailored Combination of :

- **Automation**
- **Integrated Pressing Tool**
- **Highest Heating Rate by FAST/Hybrid**
- **Multiple Cavity Pressing Tools**
- **Decoupling of Process Steps**
- **...**

FCT Technical Center



- Job orders
- Development support
- Training programs
- System solutions
- Own R&D department
- Expertise of FCT specialists



Induction Heated Vacuum Sintering Furnace FS I

Properties	
Temperature	RT – 2500°C
Usable volume	800 x 800 x 2000 mm
Options	Debinding Fast Cooling
Gas pressure	ABS: $< 5 \cdot 10^{-2}$ mbar REL: up to 60 mbar
Working gases	Ar/N ₂ /CO/Other

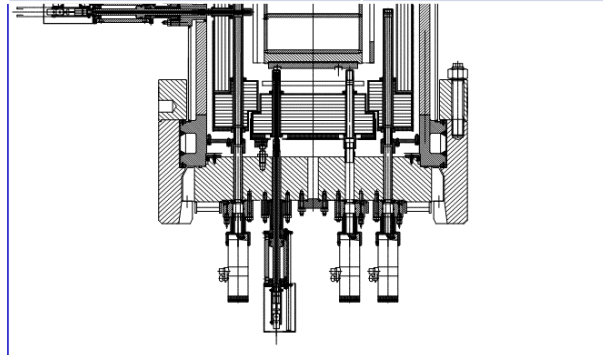


Gas Pressure Sintering Furnace FP W 90



Properties

Temperature	RT – 2200°C
Usable volume	∅ 350 x 700
Option	Debinding dewaxing
Gas pressure	ABS: $< 5 \cdot 10^{-2}$ mbar REL: up to 60 mbar High pressure: up to 100 bar
Working gases	Ar/N ₂ /H ₂ /Other Control of gas mixture



Resistance Heated Hot Press with Gas Pressure HP P

Properties	
Pressing force	max. 50 t
Temperature	RT – 2400°C
Sample size	Ø40 – 150 mm
Usable volume	Ø 200 x 250
Option	debinding
Gas pressure	ABS: $< 5 \cdot 10^{-2}$ mbar REL: up to 60 mbar High pressure: up to 10 bar
Working gases	Ar/N ₂ /Other



Hybrid Heated FAST/SPS Furnace H-HP D 25-FL

Properties	
Pressing force	max. 25 t
Temperature	RT – 2400°C
Sample size	Ø20 – 100 mm
Heating power	FAST/SPS: 120 kW Induction: 120 kW
Gas pressure	ABS: $< 5 \cdot 10^{-2}$ mbar REL: up to 60 mbar
Working gases	Ar/N ₂ /Other
Option	Flash Sintering 180 V; 200 A; 15 kW



Hybrid Heated FAST/SPS Furnace H-HP D 320

Properties	
Pressing force	max. 320 t
Temperature	RT – 2400°C
Sample size	Ø80 – 350 mm
Heating power	FAST/SPS: 400 kW Induction: 400 kW
Gas pressure	ABS: $< 5 \cdot 10^{-2}$ mbar REL: up to 60 mbar
Working gases	Ar/N ₂ /Other



Course of a Typical Customer Project at FCT Systeme

- Customer's idea
- 1st contact and discussion
- Non disclosure agreement
- Literature study
- Creation of work plan for 1st project phase
- Raw material delivery
- Lab scale test cycles
- Sample characterization and assessment of the results
- Upscaling
- Concept & design of pilot plant / serial production plant



The Circle of Success

**Process & Technology
Know-how**

**Technical
Center**

**After-Sales
Service**

**Intense Quality
Management**

**German
Engineering
Excellence**



Thank you

for your attention!



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