Gas-enabled excellence.
Influence of industrial gas in AM.
AM value chain

- Powder production
- Powder handling
- 3D printing
- Post processes
GDC
Additive Manufacturing
AM Lab in Munich
Capabilities

**Purpose:**
- In-house process development
- Part production

**Features:**
- Build surface 250*250*350mm
- 400W Fiber Laser, focus Ø 100 μm

**Purpose:**
- Process development
- Internal training

**Features:**
- Build surface Ø300*400mm
- 500W Fiber Laser, focus Ø 100-500 μm

**Purpose:**
- Process development
- Internal training

**Features:**
- Build surface Ø100mm
- 200W Fiber Laser, focus Ø 50 μm

6 Technology experts
3 PhD students
1 Marketing/Partner management
1 Engineering

**Analytic:**
- Powder characterisation (SEM, CAMSIZER X2, KarlFischer Titration, Revolution)
- Metallography lab
- Chemical Analysis (Leco HNO)
- Gas Analytic (Gas Chromatography, ADDvance O2 precision)
Powder atomisation

- Gas atomisation
- EIGA - Electrode Induction-melting Gas Atomisation
- Plasma atomisation

Gas:

\[ \text{Nitrogen} \quad \text{Ar} \quad \text{He} \]

N\text{2} \quad \text{Ar} \quad \text{He}\]

\[ \text{Nitrogen} \quad 14.007 \quad \text{Argon} \quad 39.948 \quad \text{Helium} \quad 4.002602 \]

+ optimized mixtures
Powder quality related to the atomisation medium

Water atomized powder
- Non spherical
- Bad flowability
- Chemical contamination (Oxide, Hydroxide, e.g.)
+ Cheap

Gas atomized powder
+ High spherical
+ Good flowability
+ High quality
- Pricing
Sieving

Powder storage
Powder sieving – as it is today

Today – Sieving under ambient air

- Higher safety issue for reactive/non reactive powder (under ambient air)
- Possibility of contamination for powders (regarding ambient air and moisture)
Powder sieving – future.

Future – Sieving under inert gas

- Improved safety for reactive powders
- Reduced potential of moisture and ambient air contamination of powders
Powder storage

Storage of sensitive powders under a humidity and oxygen free environment
What do all this AM process steps have in common?

- G A S -
Powder based Additive Manufacturing Process

- Powder bed Laser Beam Melting
- Electron Beam Melting (Vacuum)
- Laser Metal Deposition
Role of process gas in L-PBF

- Remove process by-products:
  - Keep a clean laser spot
  - Keep a clean powder bed

- Remove air:
  - Avoid oxidation
  - Keep a slight overpressure
Which parameters influence the end product quality?

**Powder**
- Flowability
- Particle size distribution
- Satellites
- Chemical composition
- Fine particles
- Morphology
- Topology
- Humidity

**Parameters**
- Laser power
- Laser speed
- Scanning speed
- Build strategy
- Hatching distance
- Layer thickness

**Machine**
- Laser, scan
- Software
- Gas flow
- Chamber size
- Recoating strategy
Which parameters influence the end product quality

**Atmosphere**
- Gas type, gas purity, humidity, atm. composition, flow speed, temperature

**Machine**
- Laser, scan, software, gas flow, chamber size, recoating strategy...

**Powder**
- Flowability, Particle size distribution, satellites, chemical composition, fine particles, morphology, topology, humidity...

**Parameters**
- Laser power, laser speed, scanning speed, build strategy, hatching distance, layer thickness...

**Atmosphere**
- Gas type, gas purity, humidity, atm. composition, flow speed, temperature
# Importance of Gas in L-PBF

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>In welding</strong></td>
<td>0,002% (20 ppm)</td>
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<tr>
<td><strong>In AM</strong></td>
<td>0,1% to 1,5%</td>
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- During welding it is commonly known to lower the oxygen concentration as much as possible to maintain anticorrosive properties
- More Oxygen will lead to oxides, mechanical variability or even pores

**Why should it be different in Laser Powder Bed Fusion?**
Composition of L-PBF Atmosphere

- Nitrogen: 78.084%
- Oxygen: 20.946%
- Argon: 0.934%
- Rest (CO₂, H₂, Humidity, etc.): 0.434%
- "Oxygen": 99.5%
Composition of L-PBF Atmosphere

- Oxygen: 0.1%
- Nitrogen: 0.37%
- Argon: 99.5%
Plastic connections are a source of leakages
Current machines do no monitor/control accurately the oxygen content

Chamber is purged until 0.1%.
During process:
• $O_2$ is not precisely monitored
• $O_2$ content is not controlled
Oxygen measurement in the chamber
ADDvance O2 precision
Control of the Oxygen in the chamber
ADDvance – O₂ precision developed by Linde
Example of O₂ variation during start

1) Recoater moves → O₂ increases
2) New powder → O₂ increases
3) Precise control of the oxygen content with Linde solution
ADDvance O$_2$® precision
Oxygen concentration
ADDvance O2 precision
Example installation EOS M290
ADDvance O2 precision
Example installation EOS M290
ADDvance™ O2 precision
Sampling point (example SLM Solutions)
ADDvance™ O2 precision
Example TruPrint1000
Influence of O2 on Ti-6Al-4V

Without O2 control

With ADDvance O2 precision
Influence of Oxygen on AlSi10Mg – Surface

Oxygen stabilizes the melt pool → better surface
Influence of Oxygen on AlSi10Mg

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<th>Speed (mm/s)</th>
<th>Density (%)</th>
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<tbody>
<tr>
<td>s=900</td>
<td>99.56%</td>
<td>s=1100</td>
<td>99.77%</td>
<td>s=1300</td>
<td>99.88%</td>
<td>s=1500</td>
<td>99.67%</td>
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<tr>
<td>100 ppm O₂</td>
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<td>s=1700</td>
<td>99.52%</td>
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<td>s=900</td>
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<td>s=1100</td>
<td>99.72%</td>
<td>s=1300</td>
<td>99.73%</td>
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<td>1000 ppm O₂</td>
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<tr>
<td>s=1500</td>
<td>99.21%</td>
<td>s=1700</td>
<td>98.33%</td>
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Density of AlSi10Mg cubes lasered with 175 W power and a constant Hatch distance of 0.16 mm at 100 ppm oxygen, S = Speed

With lower oxygen concentration:
Possible to ↗ laser speed while maintaining or even increasing part density.
Oxygen content

= 

An additional parameter!
L-PBF
Influence of Helium
Process by-products when using Argon or Helium

Argon

Helium
Process by-products when using Argon or Helium
New process gas for Ti-6Al-4V (start 2019) to increase the laser speed

Selection Criteria:
- Rel. Density $\geq 99.98\%$
- Productivity increase versus standard parameters
- Repeatable
- Moderate laser power to reduce instabilities and residual stresses

Up to 40% faster scanning speed
Today
Quality control with high-precision O₂ measurement inside the printer

Tomorrow
Increased build speeds with new process gases
Heat treatment of printed parts

Argon management for Hot Isostatic Pressing

Soft cleaning with CO$_2$ snow
Argon management for HIP
ADDvance® Cryoclean
Surface finishing

ADDvance cryoclean is a surface finishing solution using CO2 snow with or without abrasive that enables the operator to adapt the CO2 snow/abrasive ratio from gentle to abrasive.
ADDvance Cryoclean
Surface finishing with CO2 snow

With or without ATEX II conformity
CO₂ monitoring
Filter
Compressed air
6 bar, 6 m³/min
Conclusion

• **Atmosphere** in the chamber should be considered as a **process parameter**

• **Oxygen might influence**:  
  - the properties of the AM parts  
  - the melt pool dynamic and the Marangoni flow by changing the surface tension around the melt pool, leading to density changes.

• **With lower oxygen concentration** it is possible to increase laser speed while maintaining or even increasing part density.

• **Helium** instead of Argon as process gas:  
  - minimize the number of fumes and projections of Ti-6Al-4V.
  - seems to have a positive effect by enabling fumes and projections to be removed faster from the melt pool.

• A further process parameters study should confirm that **Helium** potentially offers:  
  - higher building speeds  
  - larger stable processing window  
  - leading to greater densities than Argon
Key challenges for industrialization

Productivity

Reproducibility

New materials

Education

Certification

Standardisation
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