EPIC
EUROPEAN PHOTONICS INDUSTRY CONSORTIUM

Laser Applications along Battery Manufacturing Process at ARENA2036
Stuttgart, October 24th 2023

Laser Cutting of Battery Foils

Dr. Günter Ambrosy / Dr. Jack Gabzdyl

TRUMPF

Pulsed lasers at TRUMPF

TRUMPF´s broad pulsed laser platforms enable a variety of parameter settings which offer the possibility to address all kind of applications

Scientific

- Amphos and Dira
- MOPA systems with disk and slab amplification
- IR (and green) with up to kW of laser power
- Various scientific applications

TruMicro ps/fs

- TruMicro 2000 / 5000 / 6000
- MOPA systems with fiber, disk and slab amplification
- 10 to 200 W IR, green, UV & DUV
- Micro cutting drilling, structuring, glass processing

TruMicro ns

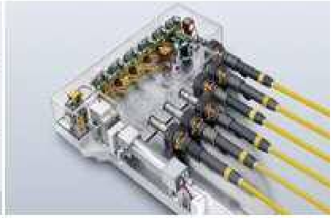
- TruMicro 7000 / 8000
- Cavity dumped disk laser
- 200 to 2000W IR, green, UV
- Cleaning, decoating, ablating, laser lift-off

TruPulse nano

- TruPulse nano 1000 to 5000
- Nanosecond MOPA fiber laser sources
- IR up to **600 W**
- Marking, cutting, drilling, welding, decoating, cleaning

TruMark

- TruMark 2000 / 5000 / 6000
- Different laser sources for IR, green & UV with scanner and marking software
- Marking, cleaning, engraving, structuring



TruPulse

- TruPulse 21 to 556
- Lamp pumped rod-type ms lasers
- 20 to 530 W IR
- Welding, drilling

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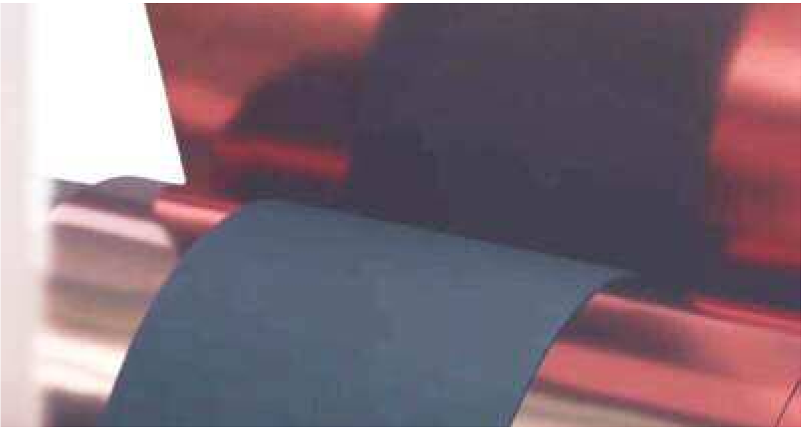
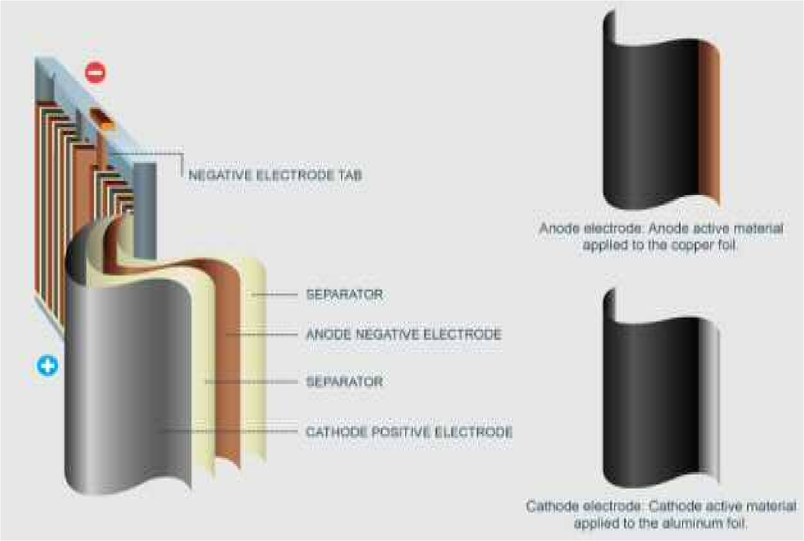
Battery foils – Anode and Cathode

Challenges due to different material combinations and cutting requirements





Electrode Foils:

Anode, Negative – Cu Foils

- **Cu Foil: 6µm – 12µm**
- **Coating: 60µm - 80µm**

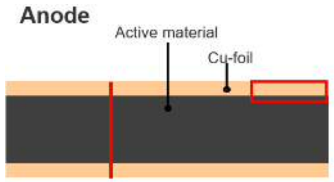
Coating typically graphite based. Highly absorbing and hence relatively easy to process

Cathode, Positive – Al Foils

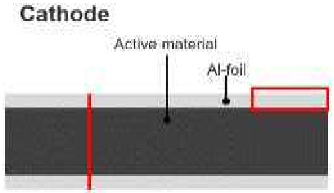
- **Al Foil: 10µm – 20µm**
- **Coating: 30µm – 100µm**
- **Optional: ceramic stripe (Al_2O_3) ~30µm.**

Composition of active materials has significant impact of cutting performance. NMC vs LFP

Examples of cutting requirements:



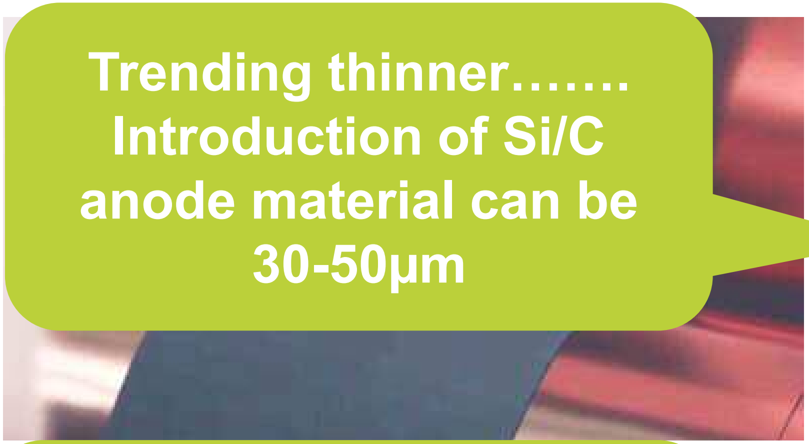
Profile cutting
Stacked battery
Anode



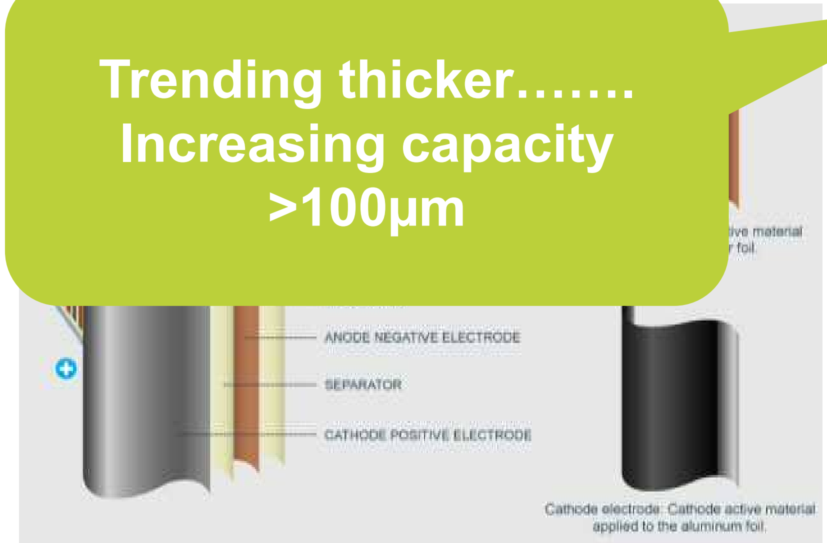
Notching
Cylindrical battery
Cathode

Battery foils – Anode and Cathode

Challenges due to different material combinations and cutting requirements



Trending thinner……. Introduction of Si/C anode material can be 30-50µm



Trending thicker……. Increasing capacity >100µm

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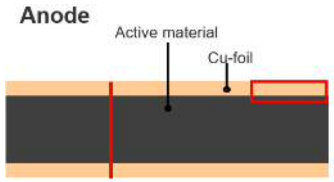

Profile cutting
Stacked battery
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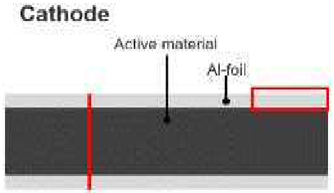

Notching
Cylindrical battery
Cathode

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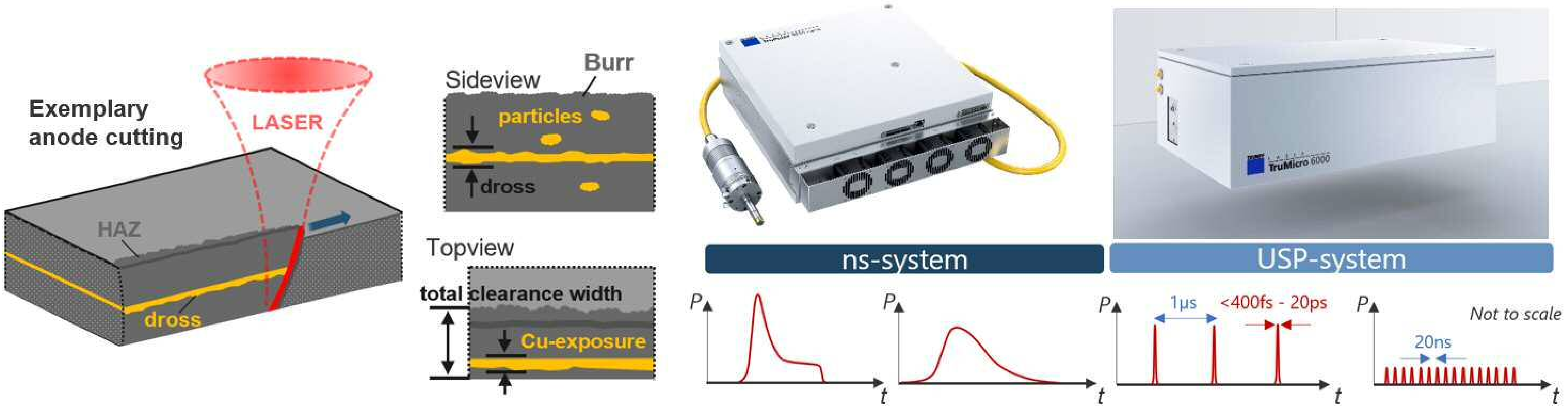
Challenges in parameter optimization

Pulsed lasers offer a tremendous bandwidth of parameter for optimization



- **Particle formation** and **metal foil exposure** as main quality criteria (risk of short circuit).

  ⇨ **Besides spot size, temporal energy deposition is a crucial parameter for optimization.**

- ***TruPulse nano*** and ***TruMicro*** laser platforms offer a tremendous bandwidth in terms of pulse durations and reprates which can be used for parameter optimization in order to address cutting speed and quality aspects.

Results
Bare foil cutting

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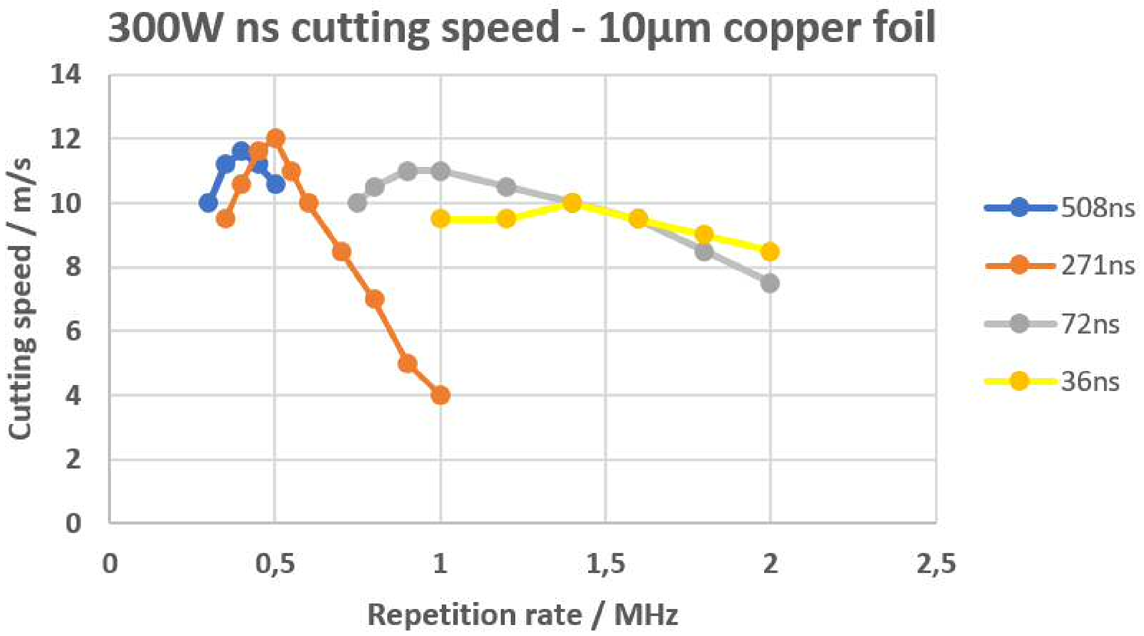
10µm Copper: Comparison of ns and USP

~3x higher efficiency of cutting by using USP (50MHz)

Nanosecond:

Setup: 10mm d_{coll} / f163mm / M²=1.6 → **~34 µm spot**



Longer pulses tend to be more efficient

- No cutting possible for cw-operation at 300W/30µm
- Need of peak power / intensity to initiate absorption
- 13kW peak power max.

Ultra-short pulse:

Setup: 5mm d_{coll} / f100mm / M²=1.2 → **~32 µm spot**

Higher reprates in general more efficient

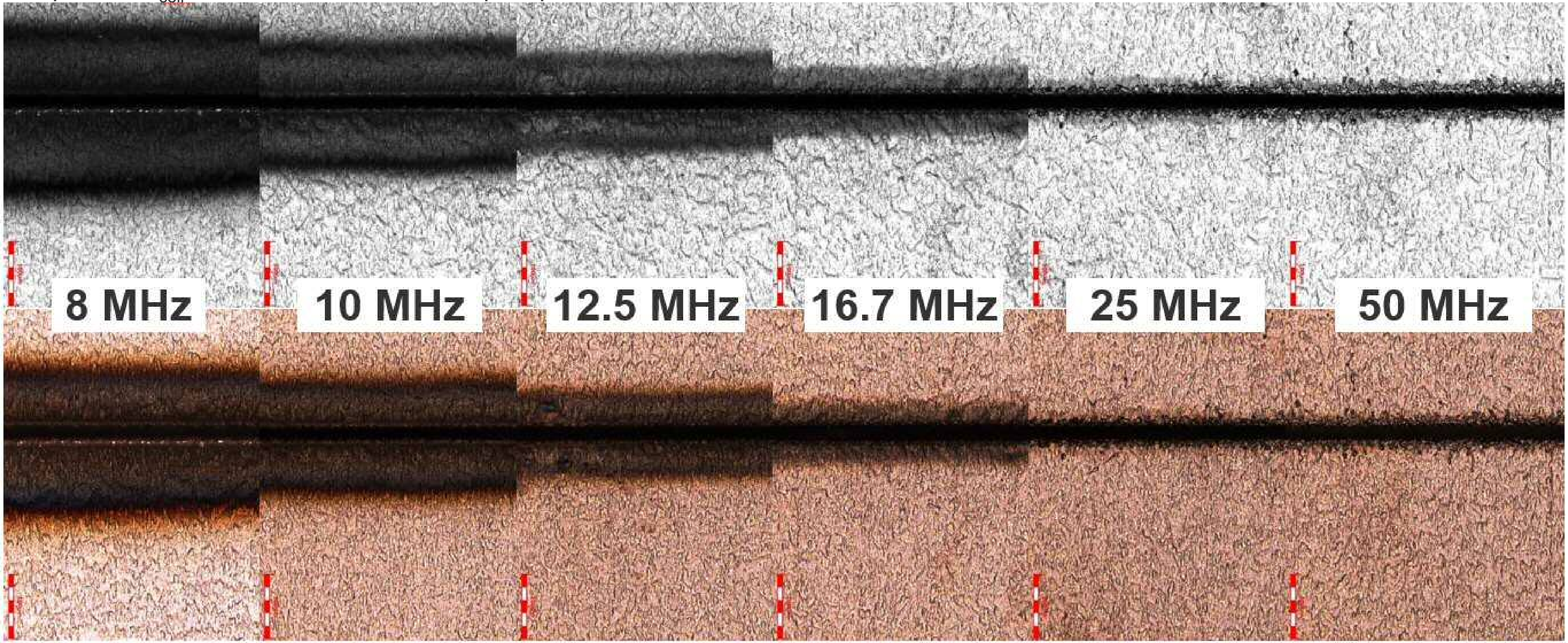
- “lowest” peak power at 100W power level was 100kW
- High peak power even at low energy levels enables cutting with high rep-rates.

High reprate USP cutting of 10µm Cu-foil: Comparison of reprates

High reprates result in significantly better qualitative appearance

100W / 1ps / 5m/s

Setup: 5mm d_{coll} / f100mm / M²=1.2 → ~32µm spot



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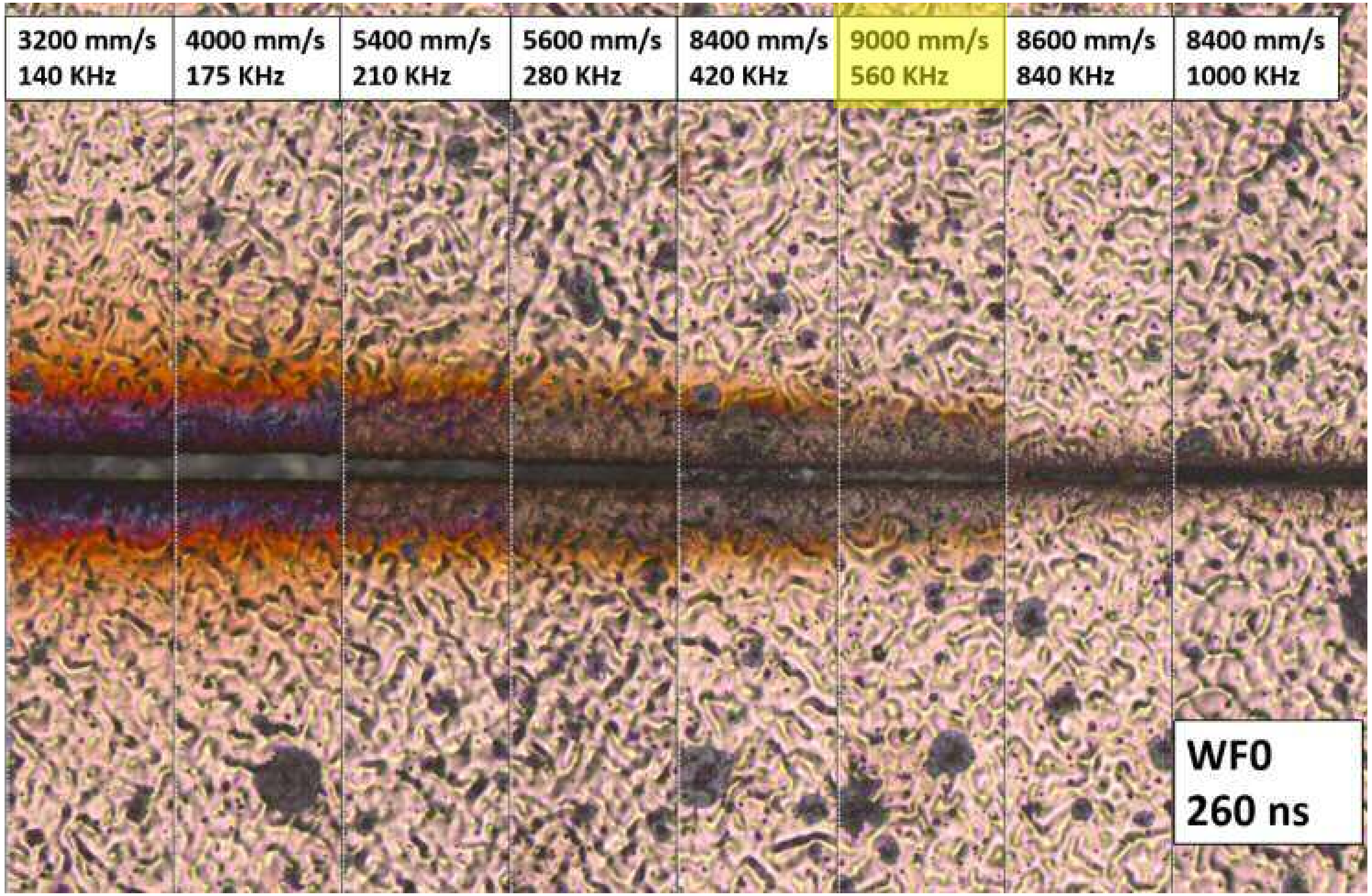
Copper cutting with ns

Findings:

- Using higher frequency results in higher speeds ⇨ peak at 560kHz
- Reduction of peak power and pulse energy impacts quality and cutting speed
- Increased speed and frequency decreases width of cut. Removing less material ⇨ faster



Results ns cutting of coated foils

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Test setup

Nano

Scanner: Raylase SS-IV

- 15mm aperture
- High speed and high dynamic tunning were used to improve cutting performance

Lens: Linos 4401-589-000-26

- Fused Silica
- Effective focal length: 163mm
- Spot diameter:
  - **~31 µm – Z-type**

Cut structure:

- Straight lines: 20mm long
- Squares: 10mm x 10mm with round corners 2mm
- Cutting speed difference: ~15%

Fixture:

- A block of metal with round hole to stretch the foil

USP

Scanner: Excelliscan 14

- 14mm aperture
- High speed and high dynamic tunning were used to improve cutting performance

Lens: Linos telecentric

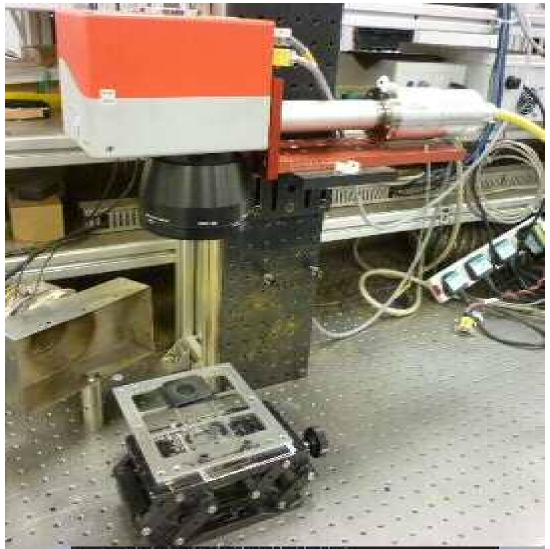
- Fused Silica
- Effective focal length: 100mm
- Spot diameter:
  - **~32 µm**

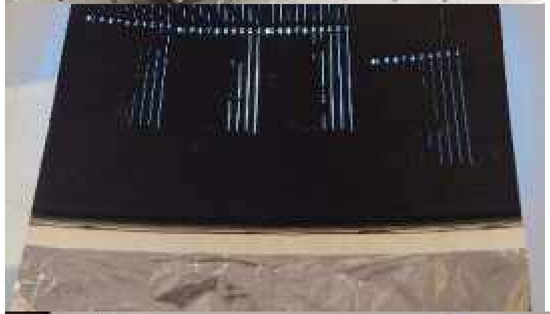
Cut structure:

- Straight lines: 20mm long

Fixture:

- Foil clamping fixture





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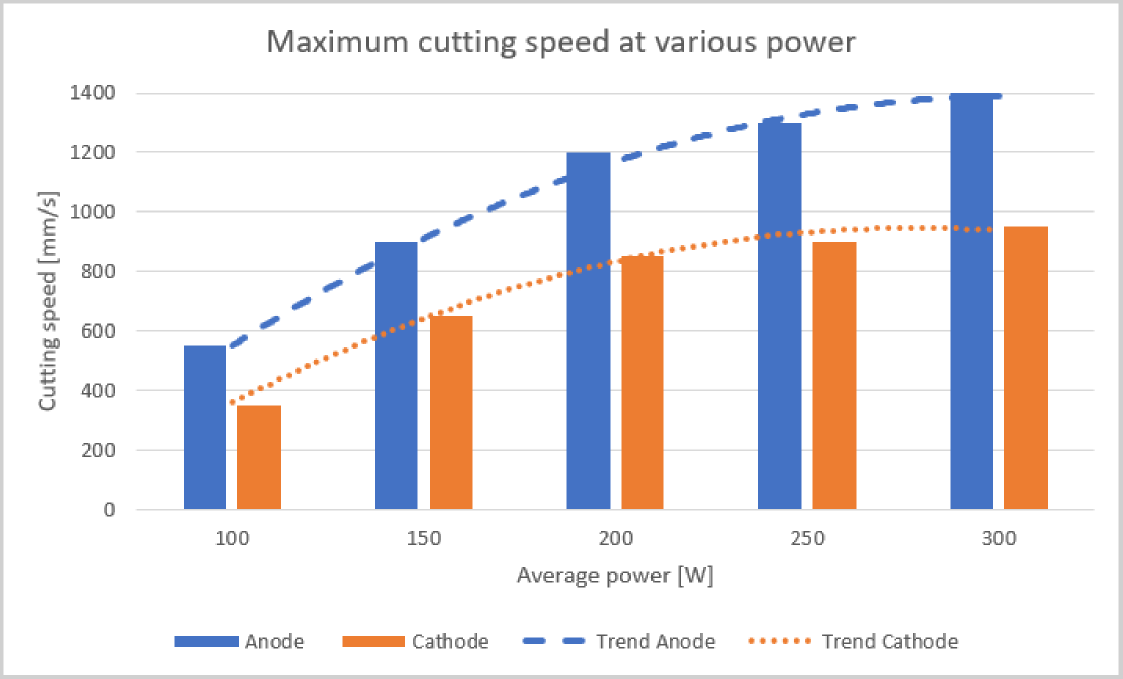
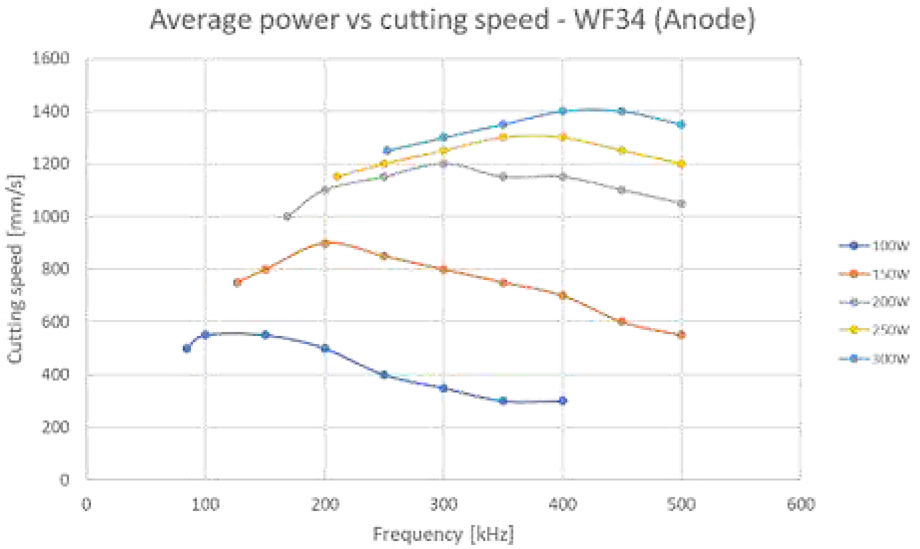
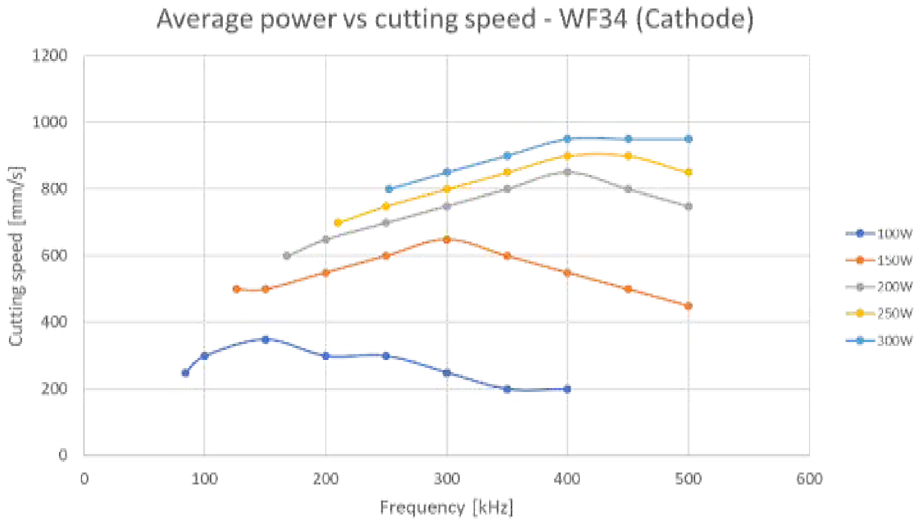
Cutting of coated foils with ns

Influence of average power







- Increasing average power yields increased productivity
- Copper in anode (10µm) requires a higher peak power with lower frequency
- Aluminium cathode needs less peak power but available increase in frequency is limited by operational constraints of the laser. Not achieving max potential from 300W

Anode cutting

General observations for ns processing

There are multiple pulse regimes that can generate fast cutting and good edge quality

- **Short pulses – < 100ns operated at high frequency**
- **Long pulses – 250-500 ns typically operated at lower frequencies**

⇨ Typically give fastest cutting speeds

- **Pulses with high peak powers (kW) and high pulse energy (mJ) do not give best results!**

⇨ **Optimisation of pulse characteristics can yield improvements in both cutting speed and edge quality.**

…but how can we get more speed?

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TruPulse nano 2060

Cutting performance on coated foils – single pass cutting

New features that enhance cutting performance.

- Extended pulse repetition frequency for long pulses - **>kHz**
- New F130 BEC to enable smaller spot size – **F130**
- New waveforms optimized for cutting application – **new WF**

**Effects can be cumulative yielding significant potential increases in cutting speed.
Not all may be applicable.**

Material	2030 300W Std WF + F100	2060 600W Std WF + F100	2060 600W > kHz + F100	2060 600W > kHz + F130	2060 600W > kHz + F130 + new WF
Anode	2.7 m/s	3.9m/s	4.4m/s	5.9m/s	7.7m/s

Note:
These are comparative results using the same material – Actual speeds may change for different foil thicknesses and material compositions

Anode cut edge quality

Quality measurements can be quite subjective – challenging

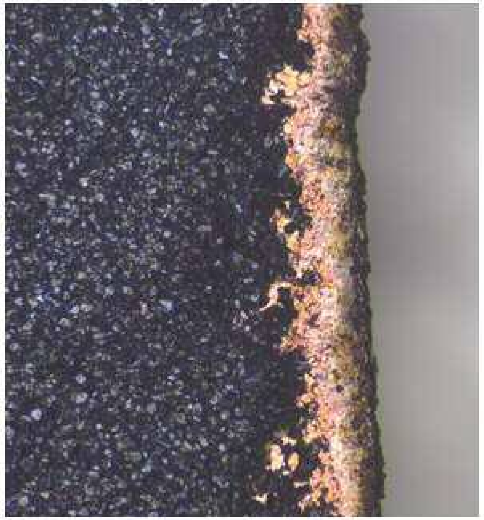
General observations:

- Heat Affected Zone (discolouration) in range 50-60µm
- Copper exposure 15 - 25µm
- Horizontal burr in range 5 - 15µm
- Vertical burr in range 10 - 20µm

Cutting speed has an impact on quality. Best quality typically achieved at close to maximum cutting speed.

Good

Very Poor



Very Poor

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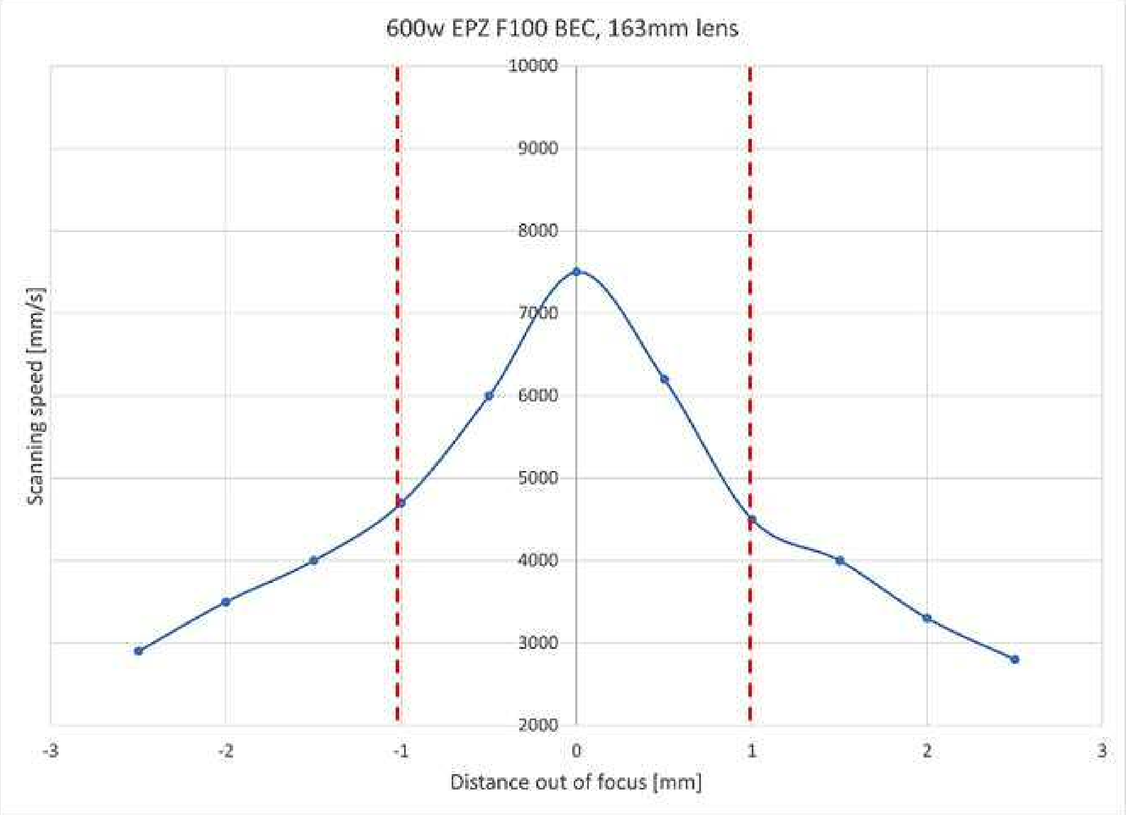
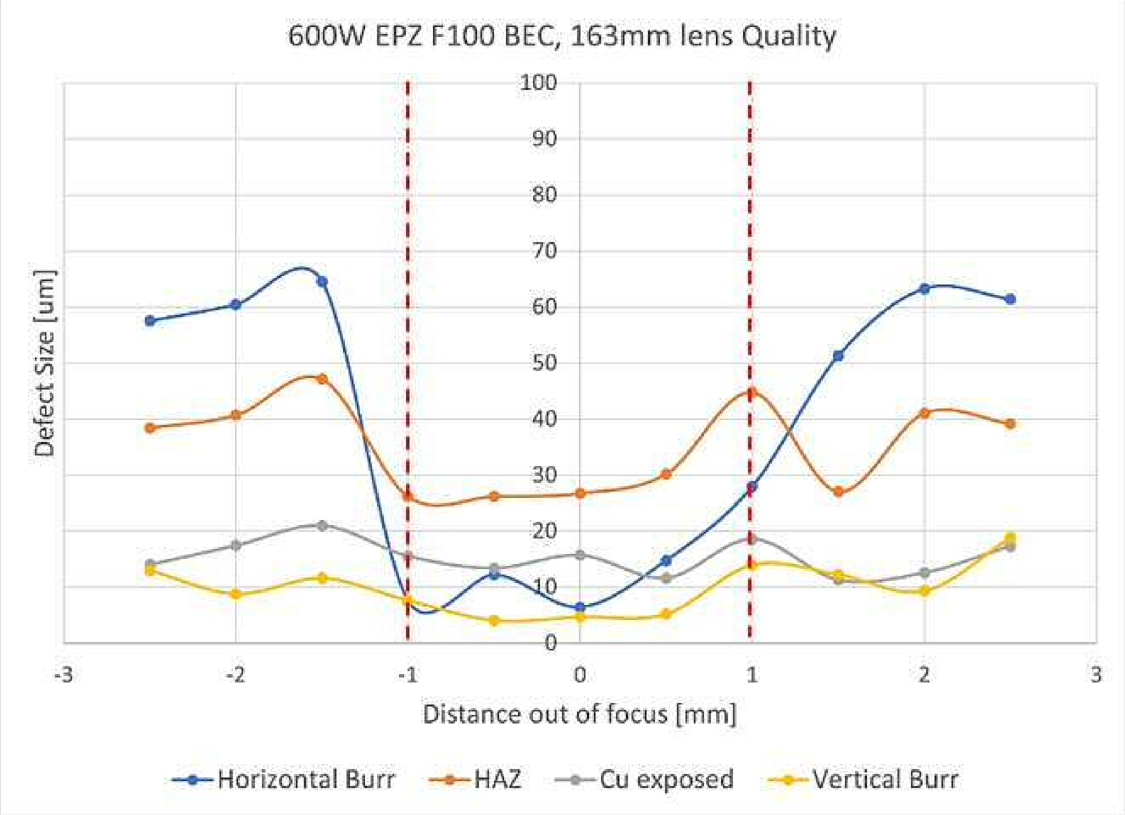
Depth of field for Anode cutting

⇨ **Maximum cutting speed can change significantly with focus position**

… but quality is less affected.





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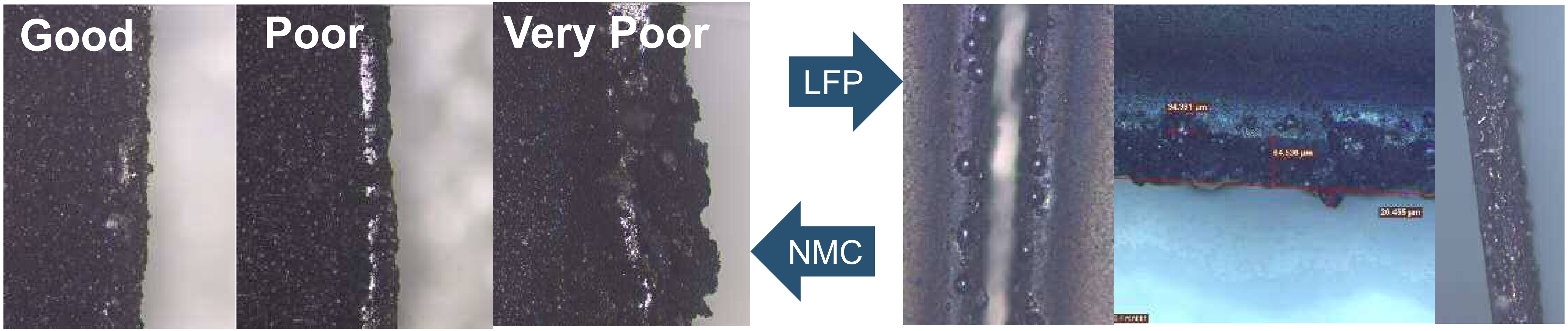
Cathode cut edge quality

Quality measurements can be quite subjective – challenging:

- Heat Affected Zone (discolouration) in range 50-70µm
- Aluminium exposure – not a problem
- Horizontal burr in range 10-20µm
- Vertical burr in range 15-25µm
- Droplet formation ~20µm
- Kerf separation – occasionally bridged

Cutting speed has an impact on quality. Best quality typically achieved at close to maximum cutting speed.



TRUMPF

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Material	2030 300W Std WF + F100	2060 600W Std WF + F100	2060 600W >kHz + F100	2060 600W >kHz + F130	2060 600W >kHz + F130 + new WF
Anode	3 m/s	4.2m/s	4.7m/s	5.9m/s	7.7m/s
Cathode -LFP	1.5m/s	1.9m/s	2.1m/s	2.3m/s	2.6m/s
Cathode -NMC	1.5m/s	1.8m/s	2.0m/s	2.2m/s	2.4m/s

Note: These are comparative results using the same material – Actual speeds may change for different foil thicknesses and material compositions

Confidential

Results ps cutting of coated foils

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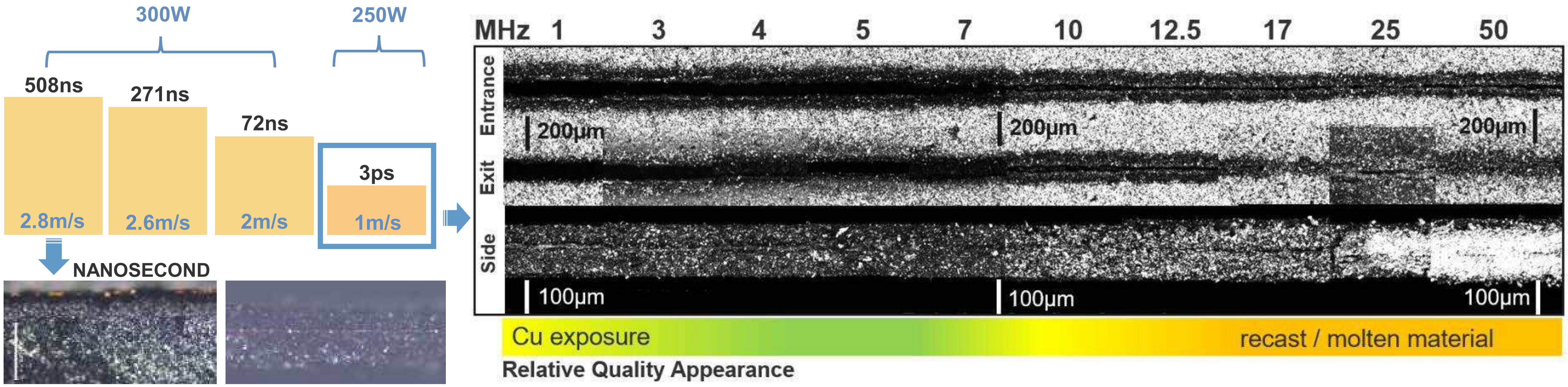
Anode cutting (Copper / Graphite): Comparison of ns and USP

TruPulse nano is able to significantly cut faster than USP-TruMicro



- At comparable cutting quality, TruPulse nano is able to significantly cut faster with a higher cutting efficiency.
- Highest cutting speed (300W) was around 2.8 m/s, whereas 250W USP was only able to reach ~ 1 m/s.
- For USP, the advantages seen on the bare foil material seem to be not present for graphite coated anode.
- USP with very high rep-rates result in recast and the formation of molten material within the cut.

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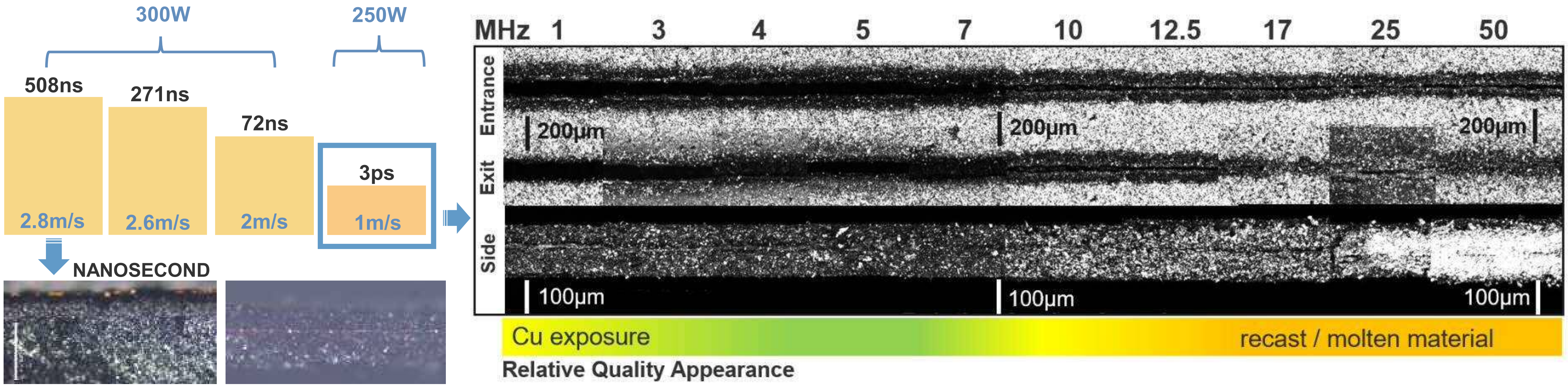

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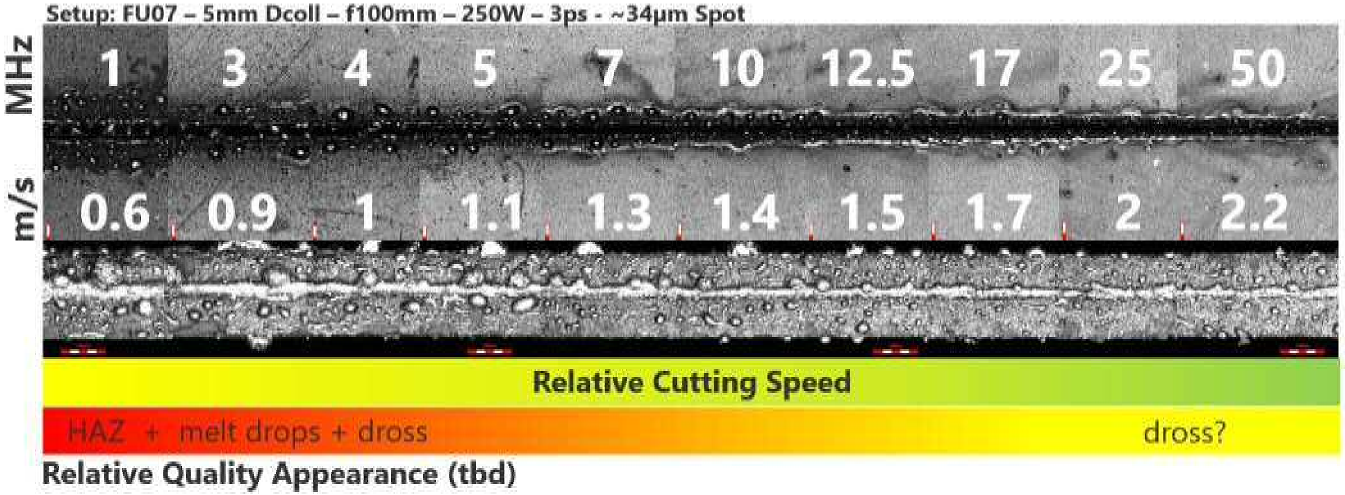
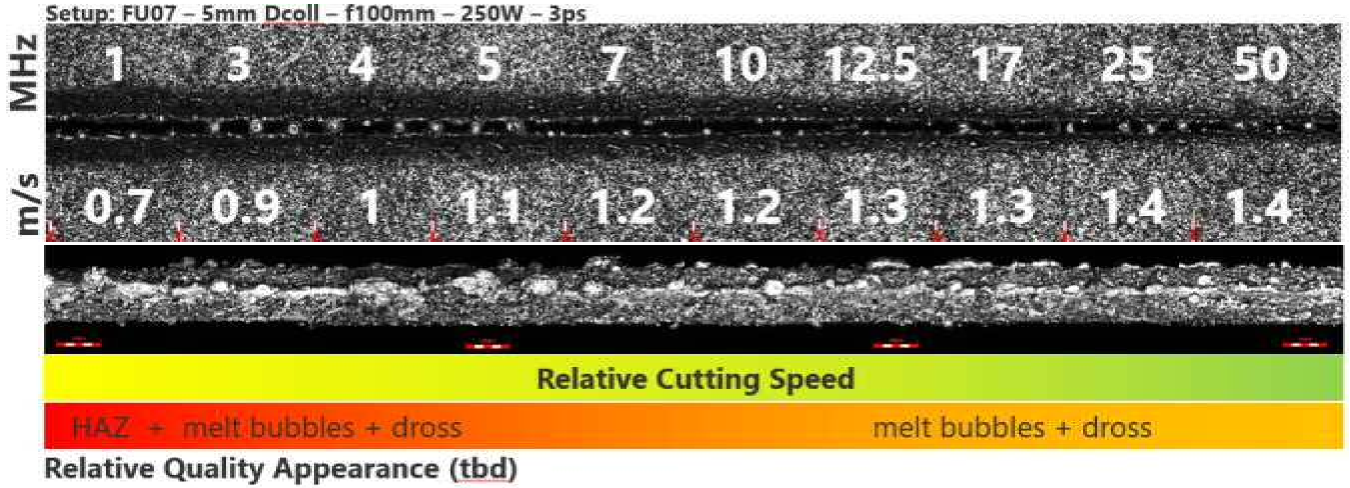
Challenge of cathode (LFP/NMC) single-pass cutting with USP

Melt-bridges & melt bubbles - main quality criteria & potential show-stopper

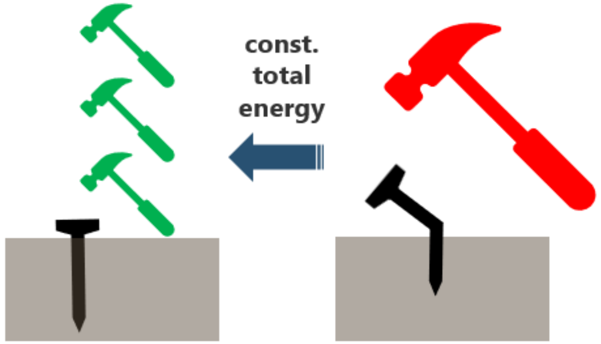
LFP



NMC



- Increase of HAZ due to excess pulse energy levels.
- Increased energy efficiency for lower energy levels leads to higher cutting speeds for higher rep-rates.
- Heat accumulation at all tested rep-rates (250W).



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TruPulse nano 2060 + TruMicro 6000

Cutting performance on coated foils

Not a like for like comparison but intended to be indicative of capability **Apples vs Oranges**

	TruMicro ps	TruPulse nano - ns cutting			
Material	250W	2060 600W Std WF + F100	2060 600W >kHz + F100	2060 600W >kHz + F130	2060 600W >kHz + F130 + new WF
Anode	1 m/s	4.2m/s	4.7m/s	5.9m/s	7.7m/s
Cathode -LFP	2.2m/s	1.9m/s	2.1m/s	2.3m/s	2.6m/s
Cathode -NMC	1.9m/s	1.8m/s	2.0m/s	2.2m/s	2.4m/s

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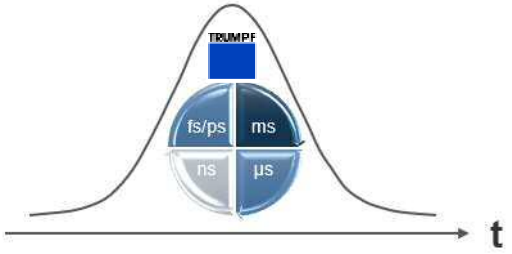
Summary



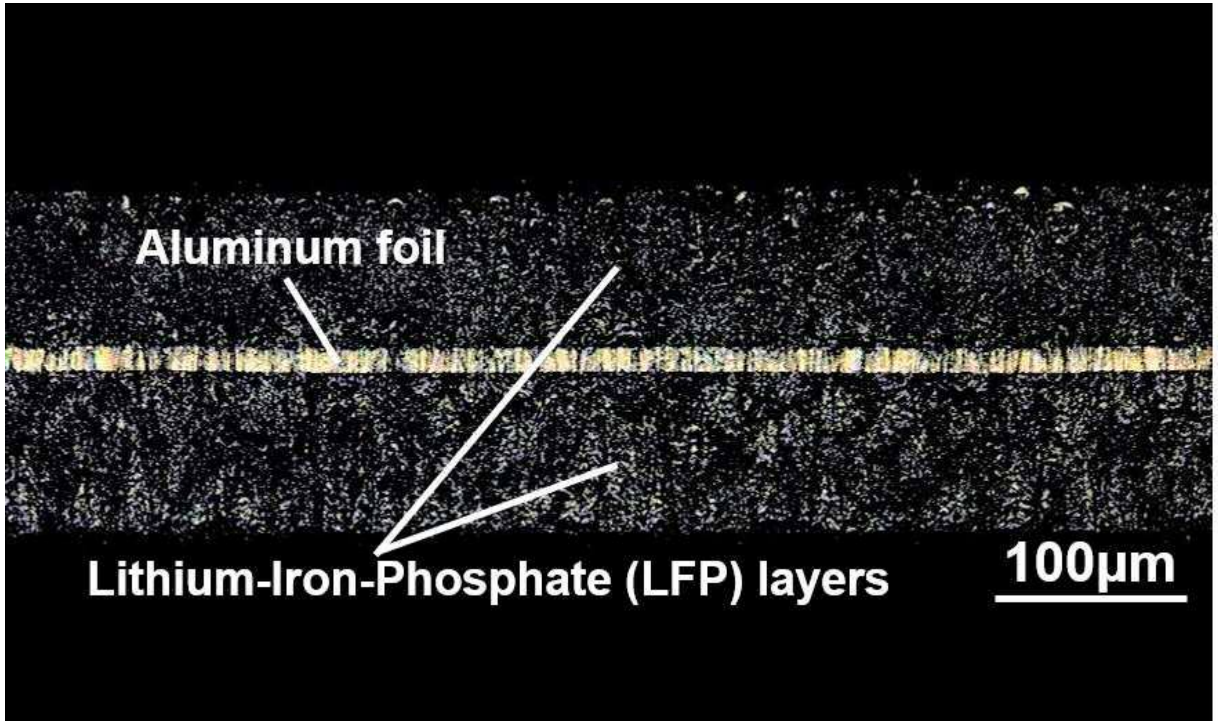
Battery foil cutting is a crucial process for EV adoption

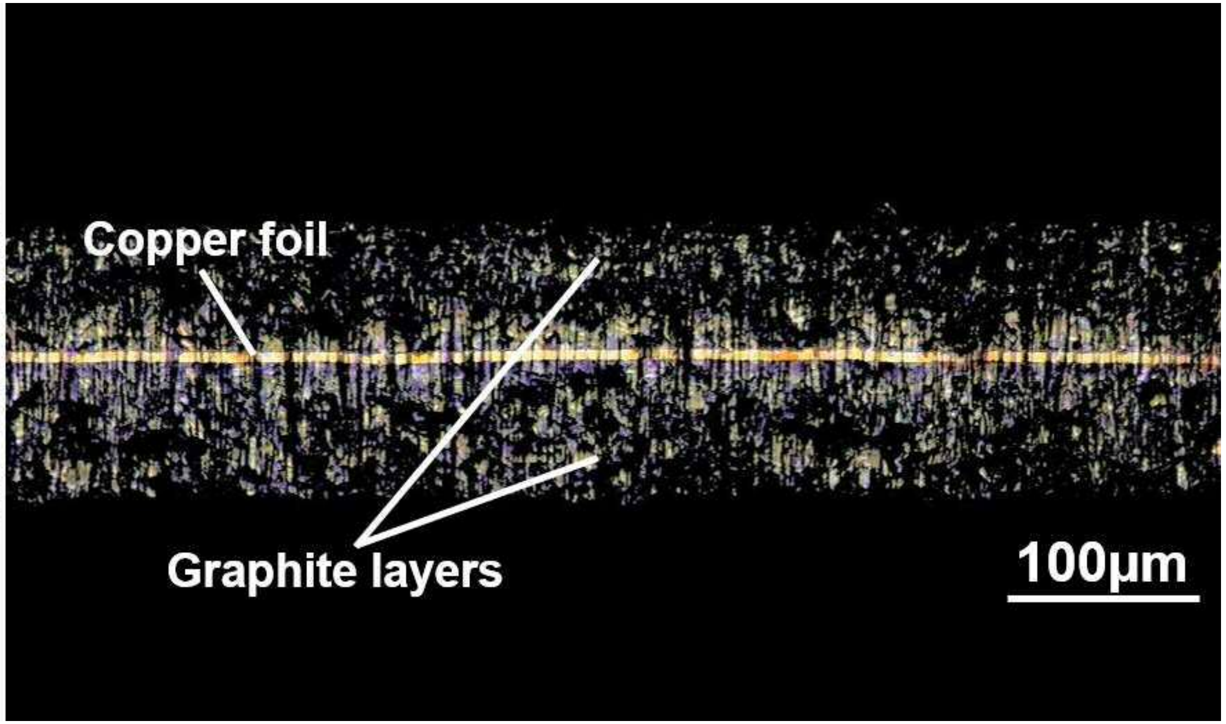
Challenges due to cutting requirements and proprietary chemistries

Flexible laser platforms like TRUMPF´s pulsed lasers can address cutting challenges

Type of laser depends on cutting speed, edge quality, and allowed material damage

Best results achieved by carefully choosing appropriate laser parameters





Investment in optimization is….
Rewarded with Performance

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