UNIVERSITÀ DEGLI STUDI DI PARMA

Advanced Lasers for Photovoltaic INdustrial processing Enhancement

The ALPINE project fiber laser micro-processing of thin-film photovoltaics

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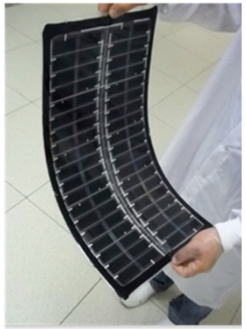
SEVENTH FRAMEWORK PROGRAMME

EU-FP7 - Large scale integrating project funded by the **European Community**
Work Programme:
Nanosciences, Nanotechnologies, Materials and New Production Technologies
Budget: **9.1 M€**
Duration: **3 years – ended 31 August 2012**
15 Partners

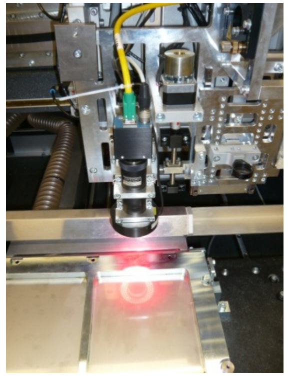
*www.**project-alpine**.**eu***

Alpine Targets

- Development of **fiber laser** based on photonic crystal fibers for the scribing of solar cells.
  MOPA and Q-switched configurations.



- Development of new PV thin films in cadmium telluride (**CdTe**) and copper indium diselenide (**CIS**) or copper indium gallium diselenide (**CIGS**). Both technologies on glass and flexible substrate.



- Improvement of the **scribing technique** in terms of accuracy and speed, by substitution of mechanical scribing by **fiber laser scribing**.

Alpine Partners

University of Parma
Italy

NKT Photonics A/S
Denmark

Solar Systems & Equipment
Italy

Würth Solar GmbH & Co.
Germany

Quanta System S.p.A.
Italy

Oclaro
Switzerland

EOLITE Systems
France

NEXCIS
France

University di Verona
Italy

European Commission Joint Research Centre
Belgium

Univerza *v Ljubljani*

University of Ljubljana
Slovenia

MULTITEL
Belgium

Zentrum für Sonnenenergie-und Wasserstoff-Forschung
Germany

Elettrosystem SAS
Italy

LPKF Laser & Electronics AG
Germany

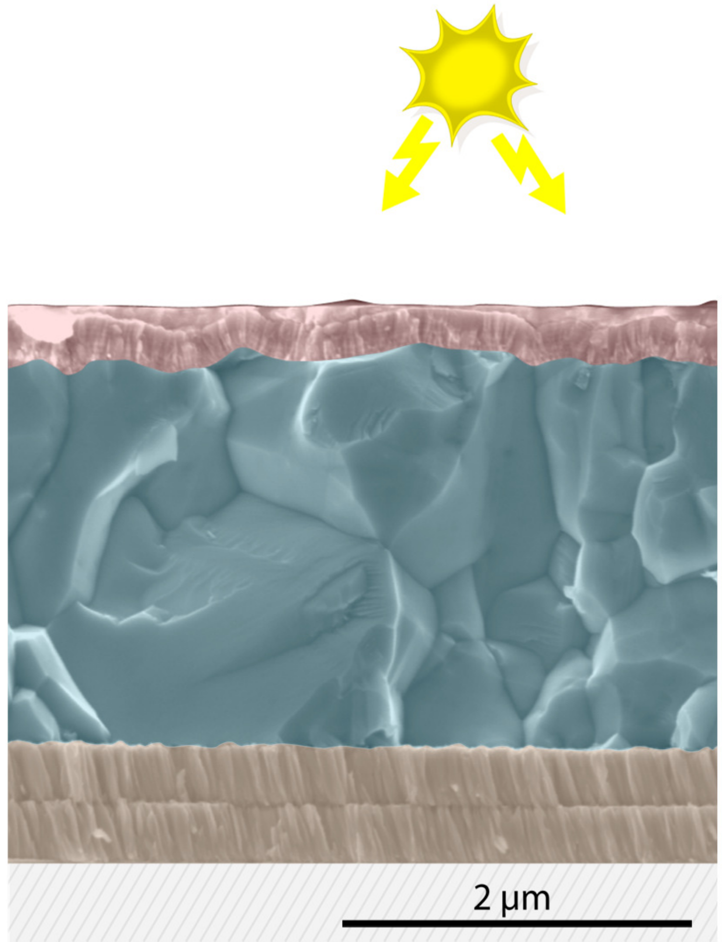
CIGS based cell

ZnO, ITO
2500 Å
CdS
700 Å

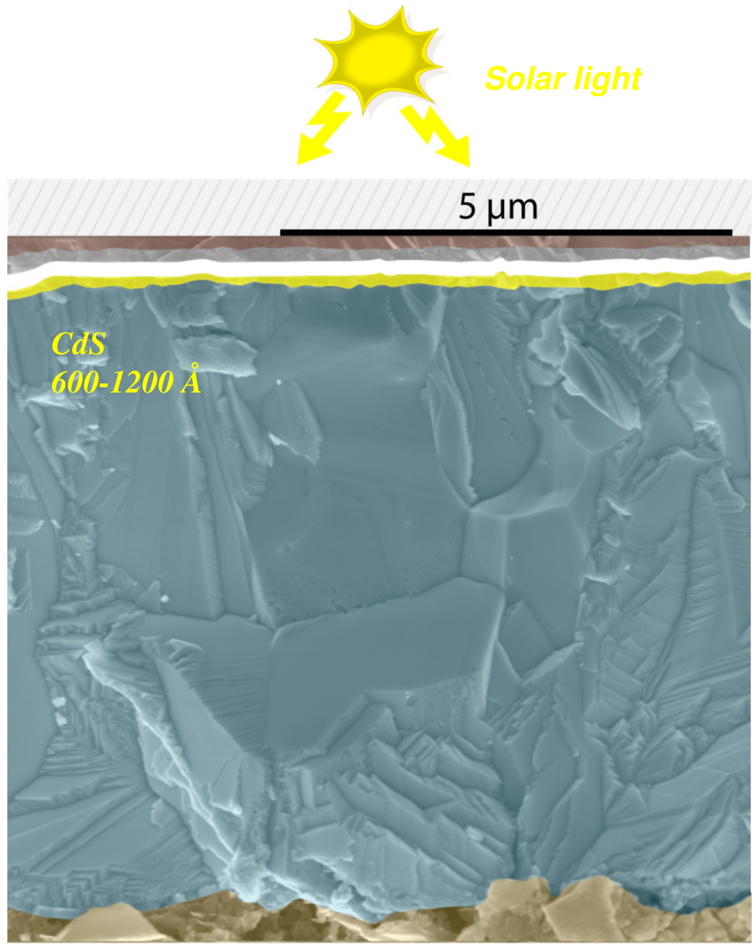
CIGS
1-2.5 µm

Mo
0.5-1 µm

Glass,
Metal Foil,
Plastics



CdTe based cell



Glass

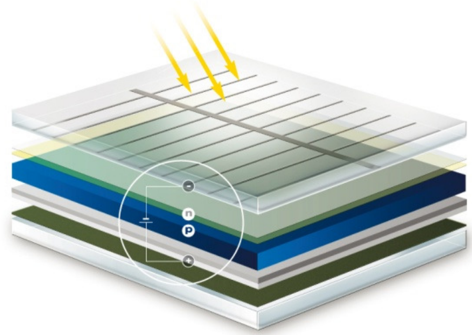
ITO 0.4 µm
ZnO 0.2 µm

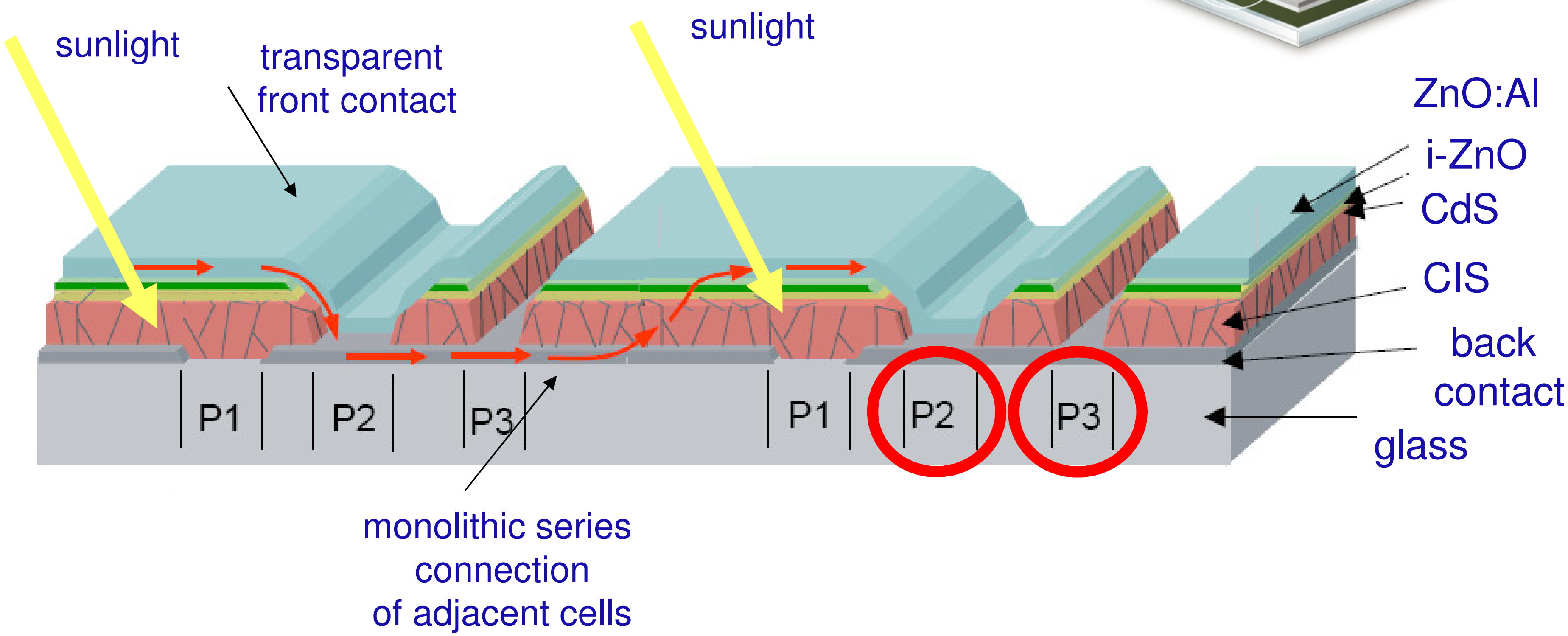
CdTe
2-8 µm

AS_2Te_3 0.2 µm
+ Mo 0.2 µm

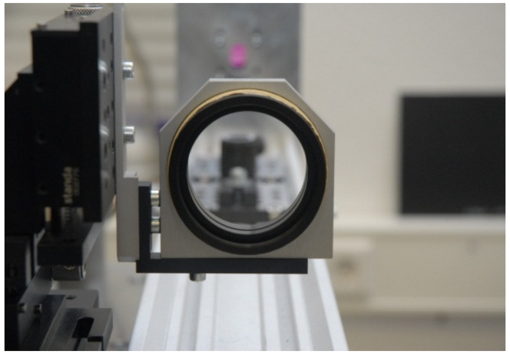
Photovoltaic module

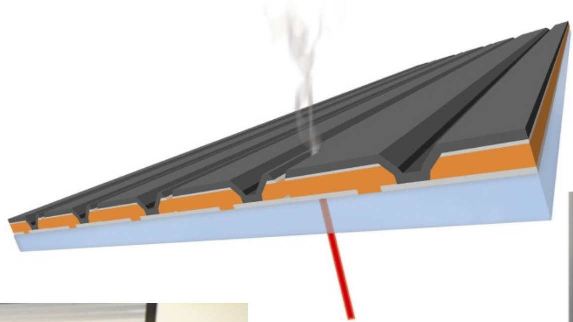
Substrate buildup

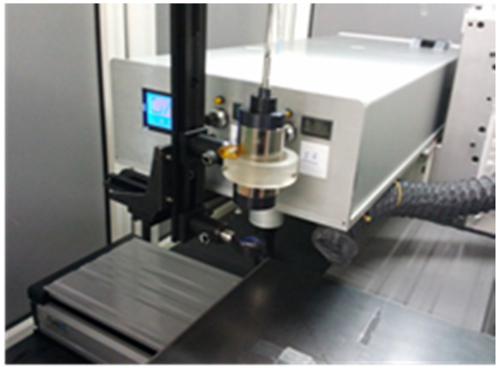


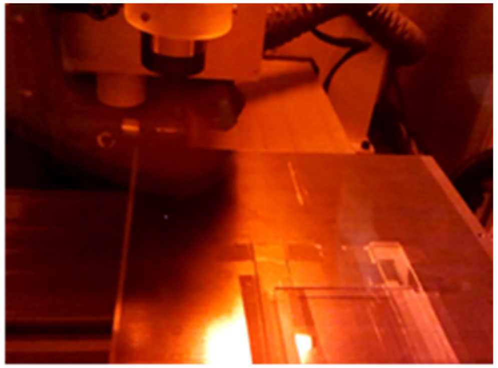


Scribing machine





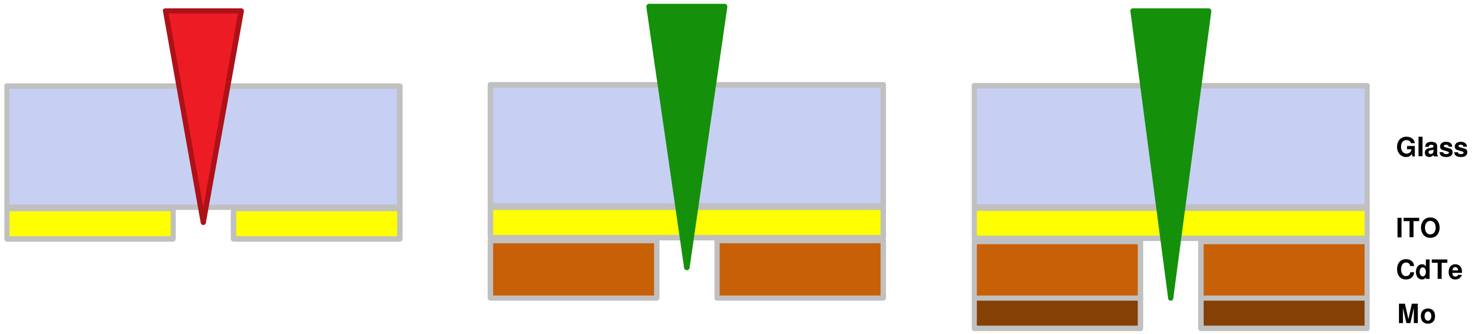




Scribing steps

IR: 1064nm, 1030 nm

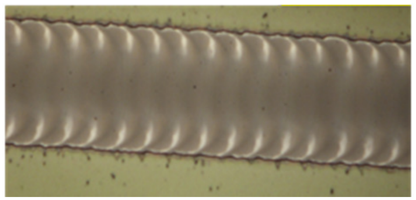
Green: 532 nm, 515 nm

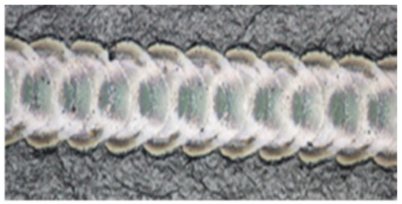


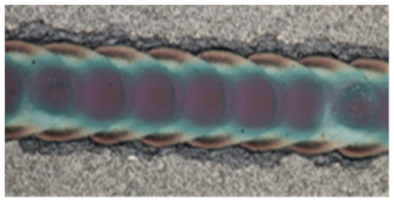
P1

P2

P3







P1

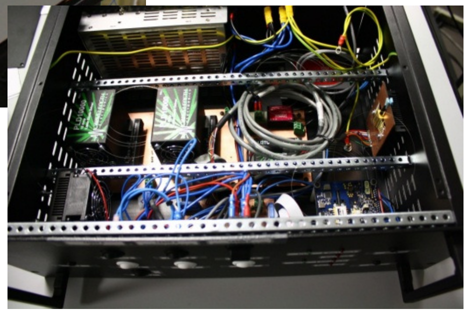
Groove width	60 - 70 µm
Lateral pulse overlap	≈ 50% - 70%
Pulse duration	≤ 40 ns
Pulse energy	≈ 200 µJ
(Mo layer thickness	≈ 300 nm)
Wavelength	1064 nm

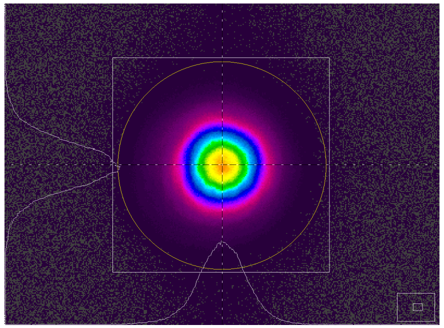
P2

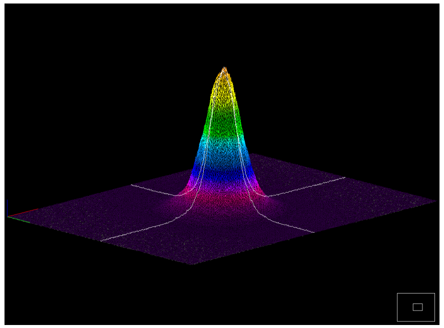
Groove width	≈ 30 µm
Lateral pulse overlap	≈ 50% - 90%
Pulse duration	≤ 10 ns
Pulse energy	≈ 100 µJ
Wavelength	532 nm
Pulse rate	High

P3

Groove width	few µm
Lateral pulse overlap	≈ 50%
Pulse rate	> 100 kHz
Pulse duration	≤ 100 ps
Pulse energy	a few µJ
Wavelength	355 nm

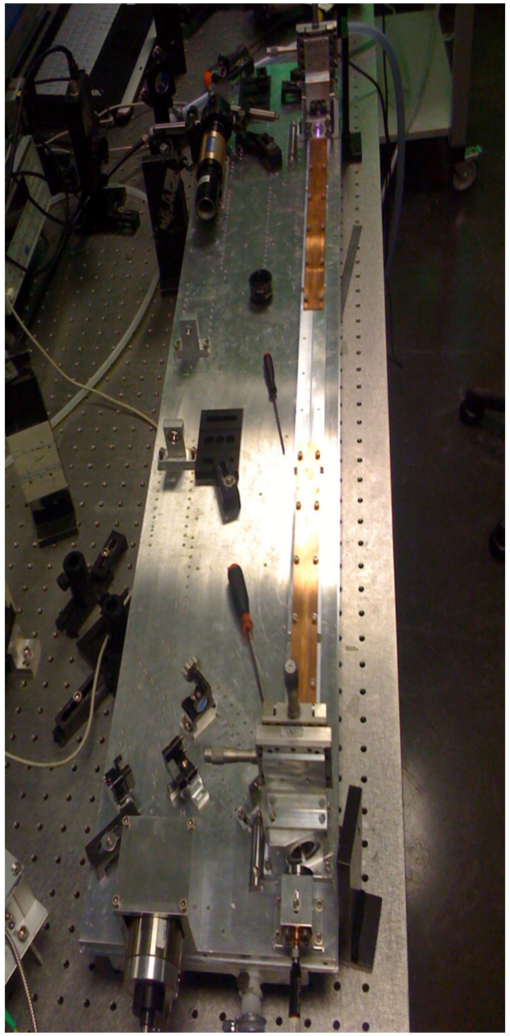


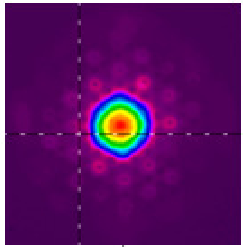


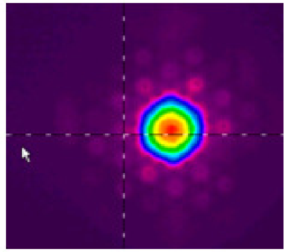


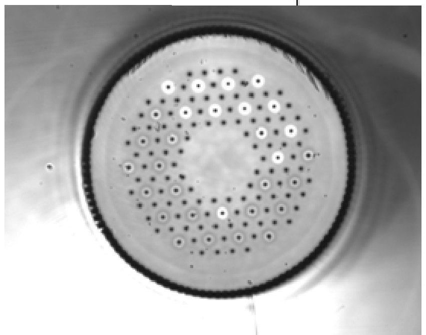
$M^2 = 1.1$

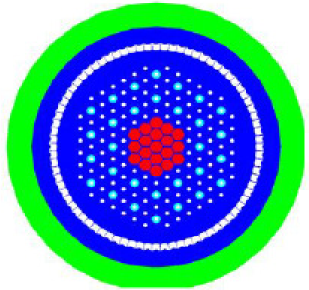
Booster stage

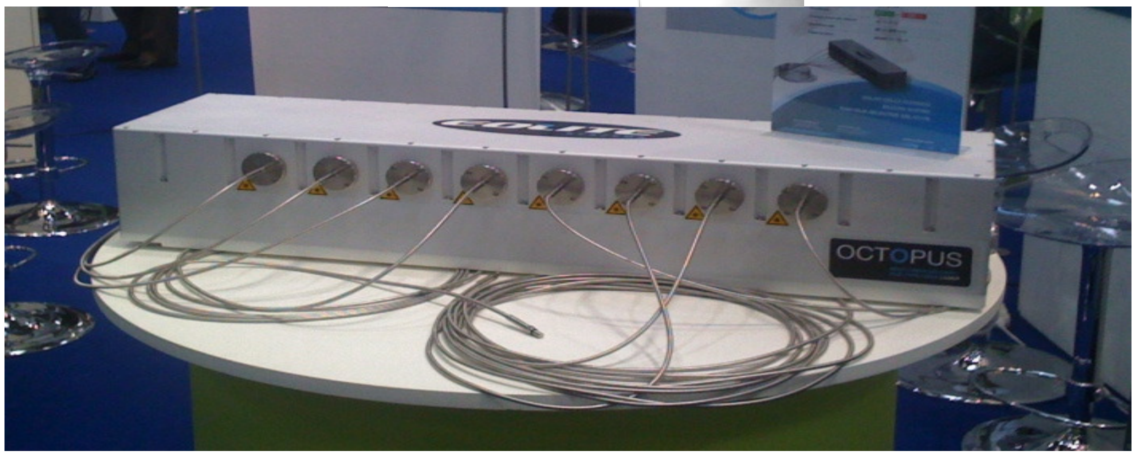












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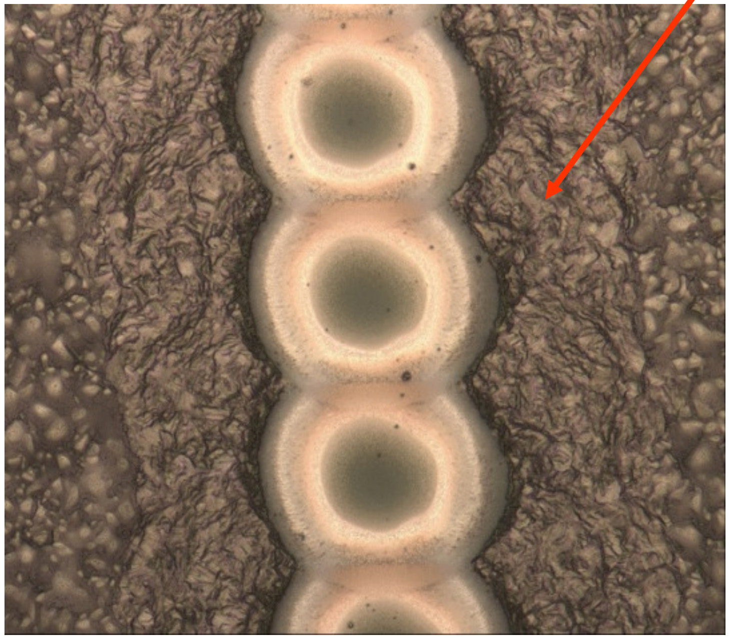
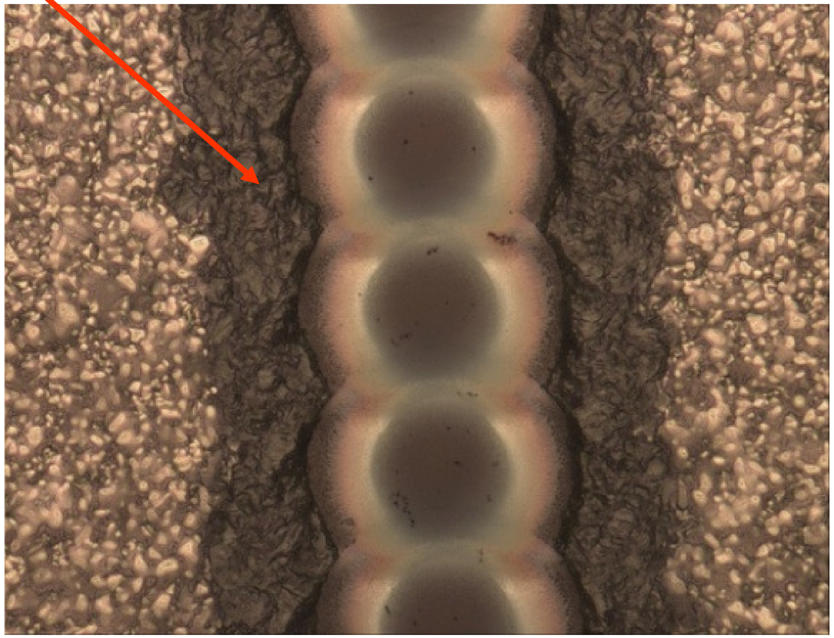
HAZ (Heat Affected Zone)



Scribing P_2, RR=32 kHz P=0.4 W



Scribing P_3, RR=35 kHz P=0.5 W

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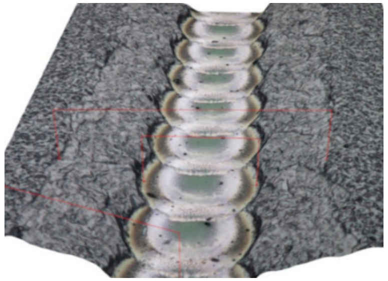
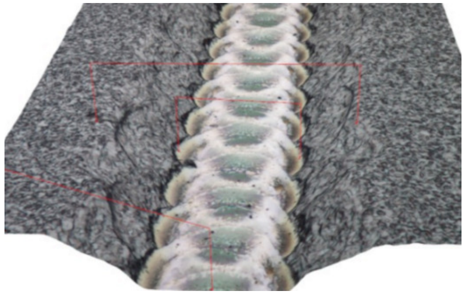
P2 tests on CdTe layers

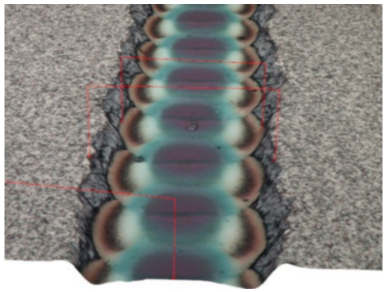


60 kHz
8 µJ
250 ps
width of the groove: 50 µm,
depth: 6 µm
width of damaged area: 32 µm

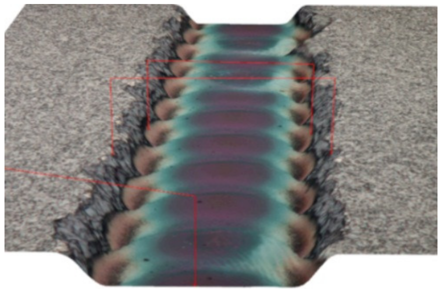


80 kHz
10 µJ
250 ps
width of the groove: 50 µm
depth: 8 µm
width of damaged area: 26.5 µm

While the width of the groove is perfectly aligned with the standards required for P2, the width of the damaged area is quite larger than that which is normally considered acceptable. A large thermally damaged area means a high probability of having shorted the junction and then all the cell.



60 kHz
8 µJ
250 ps
width of the groove: 52 µm
depth: 3 µm
width of damaged area: 7 µm

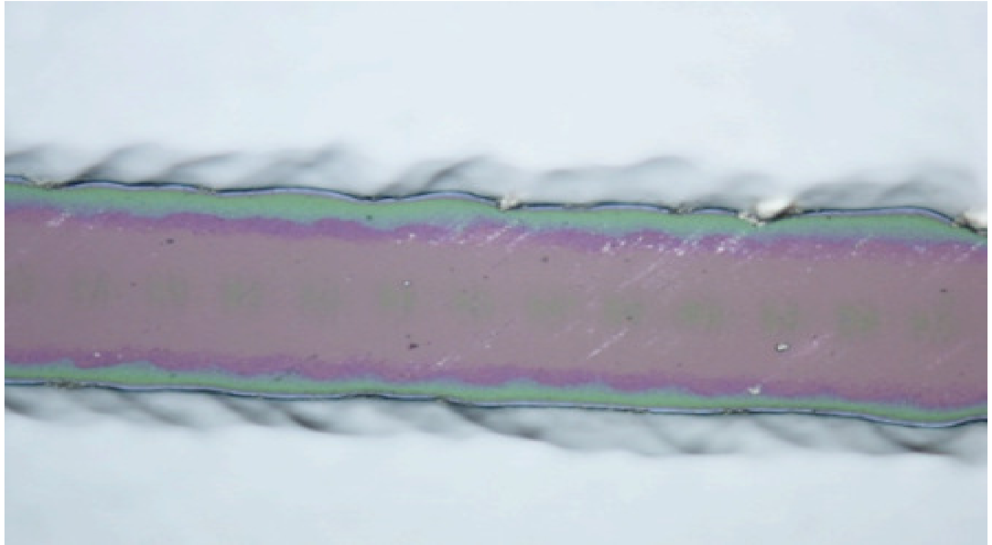


80 kHz
8 µJ
250 ps
width of the *groove*: 52 µm
depth: 6 µm
width of the damaged area: 6 µm

The edges of the groove are very clean and sharp.
The HAZ has a negligible effect and in some parts is almost totally absent.

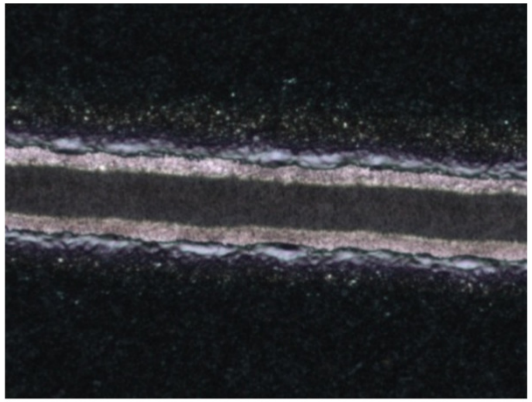
P2 photo of the scribing after chemical etching

To check the status of the TCO film underneath the laser scribed area a chemical selective etching was made in order to completely remove the CdTe/CdS layers leaving intact the TCO layer surface.

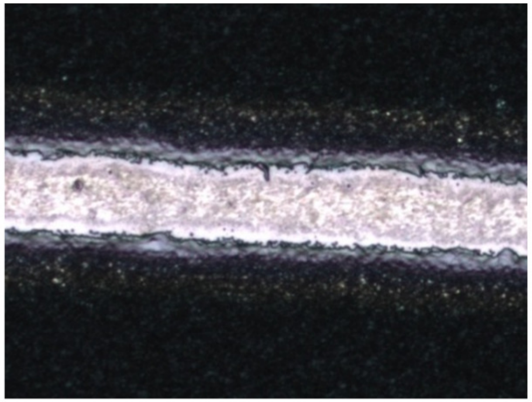


The result shown in this photo verify the TCO layer is completely clean and in perfect condition.

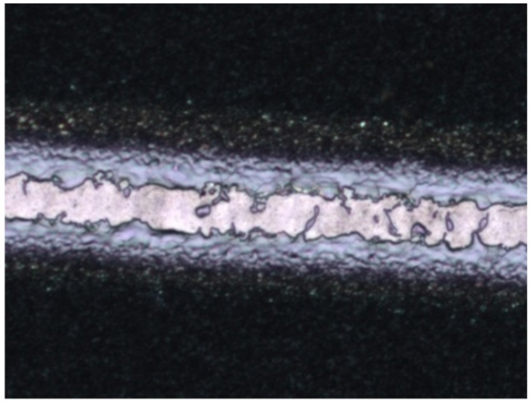
Various P2 scribing on CIS obtained with different pulses duration energy and scanning speed



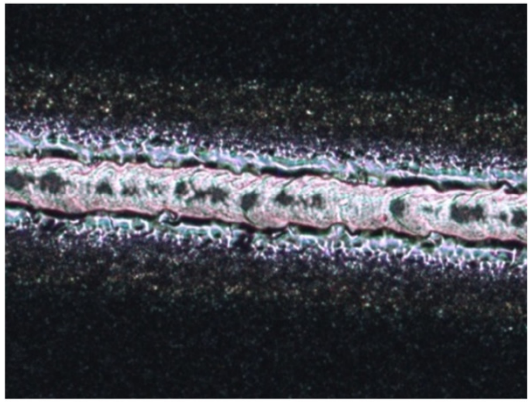
(a) 100 kHz – 900 mW – 8 ps – 40 mm/s



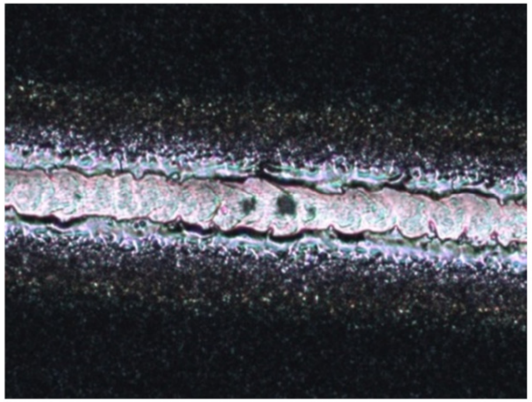
(b) 100 kHz – 900 mW – 8ps - 50 mm/s



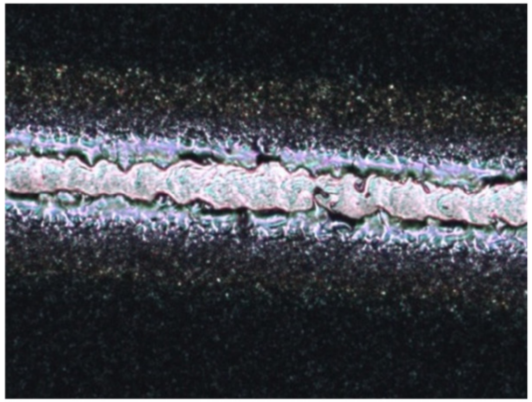
(c) 100 kHz – 900 mW- 8 ps – 80 mm/s



(d) 100 kHz – 1W – 400 fs – 80 mm/s



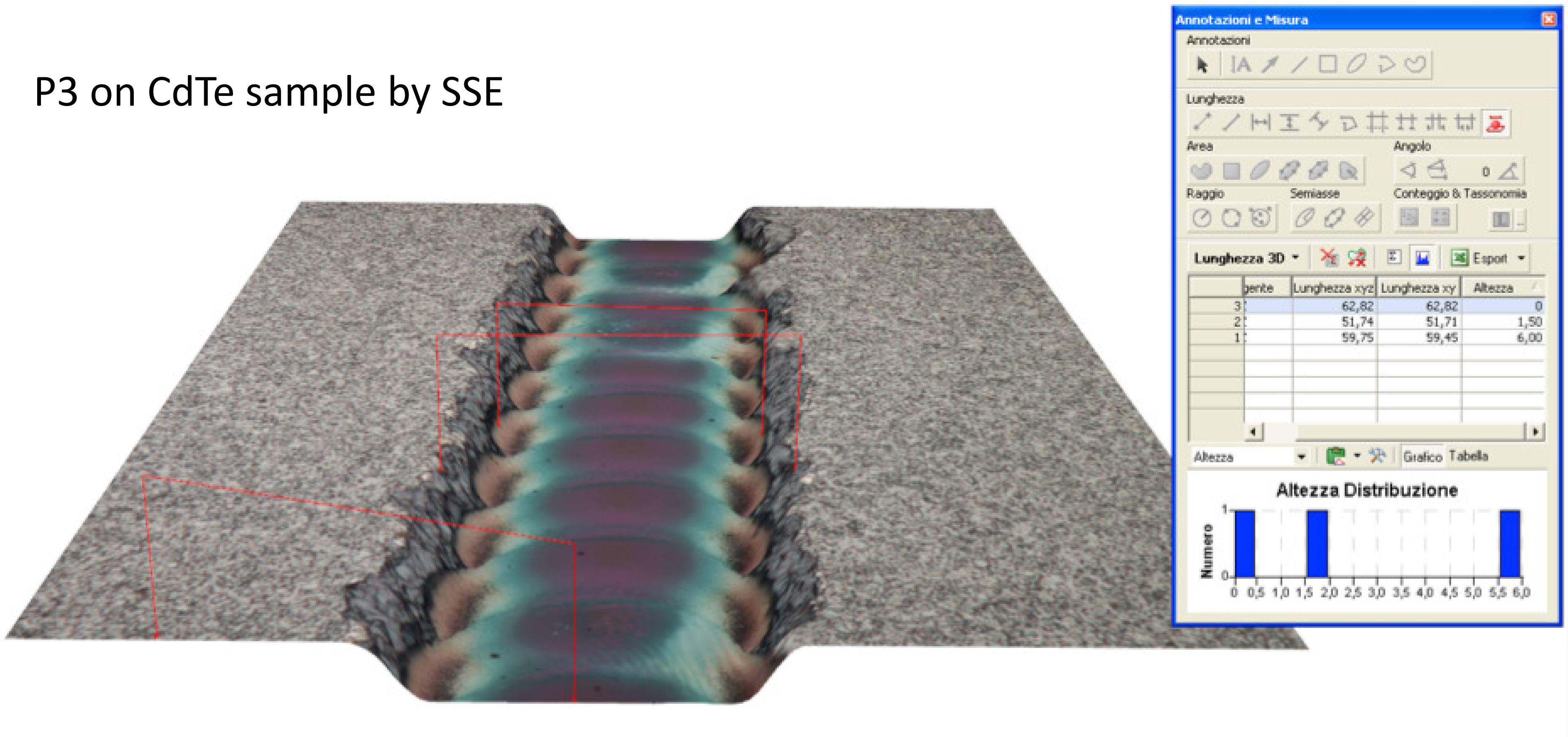
(e) 100 kHz – 1W – 400 fs – 90 mm/s



(f) 100 kHz – 1W – 400 fs – 100 mm/s

Best result obtained for 8 ps, 100 kHz, 0.9 W and 50 mm/s (picture b). In the other cases, or the Mo layer was damaged (pictures a, d and e) or important melting appeared (c, e and f).

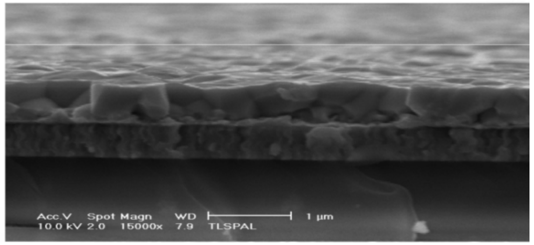
P3 on CdTe sample by SSE

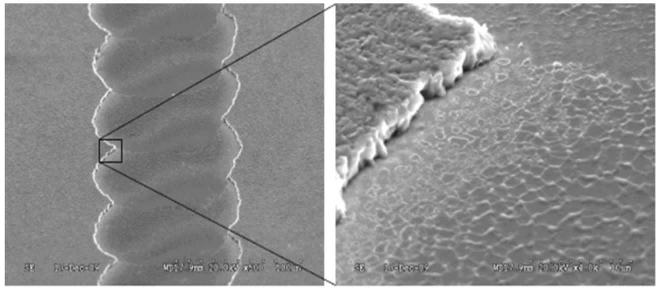


1. Width of the groove ≈ 52 μm
2. Depth of the groove ≈ 6 μm
3. Width of the damaged area (HAZ) ≈ 62 μm

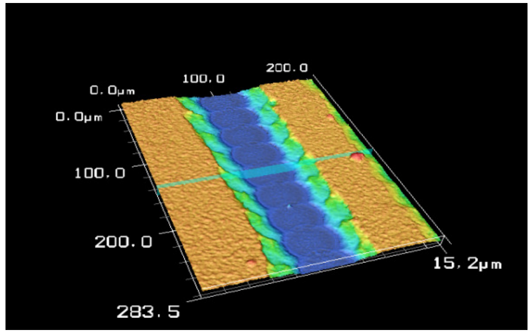
Validation

- Efficiency
- Homogeneity

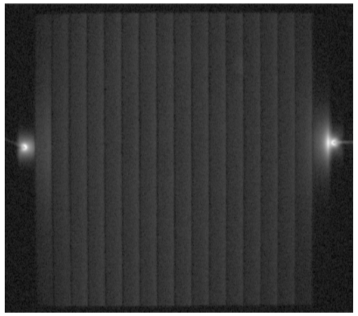




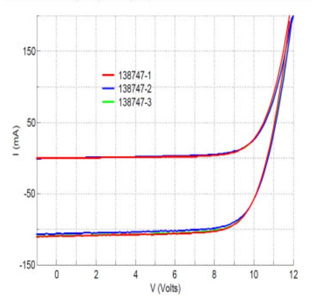
- Quality of the scribed groove



- Dimensions and HAZ



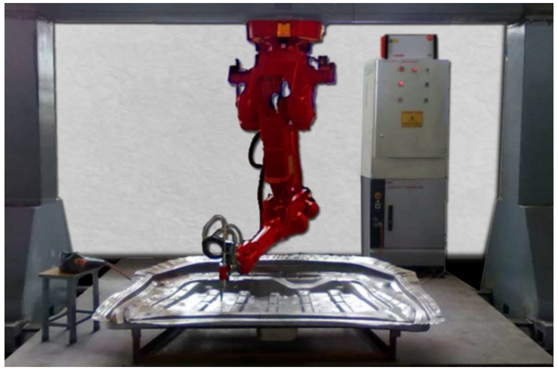
- Thermography tests
- Electrical characterization



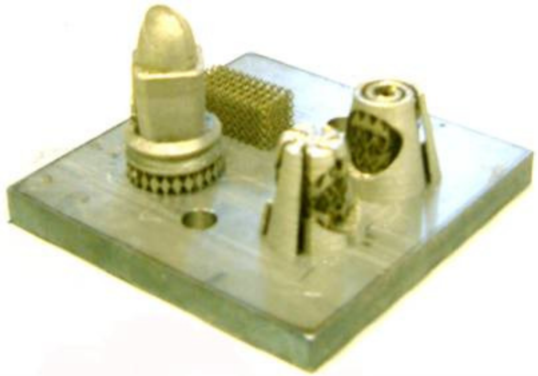
Market impact

Important market impact for each industrial partner.

Applications (processing, medical, …)



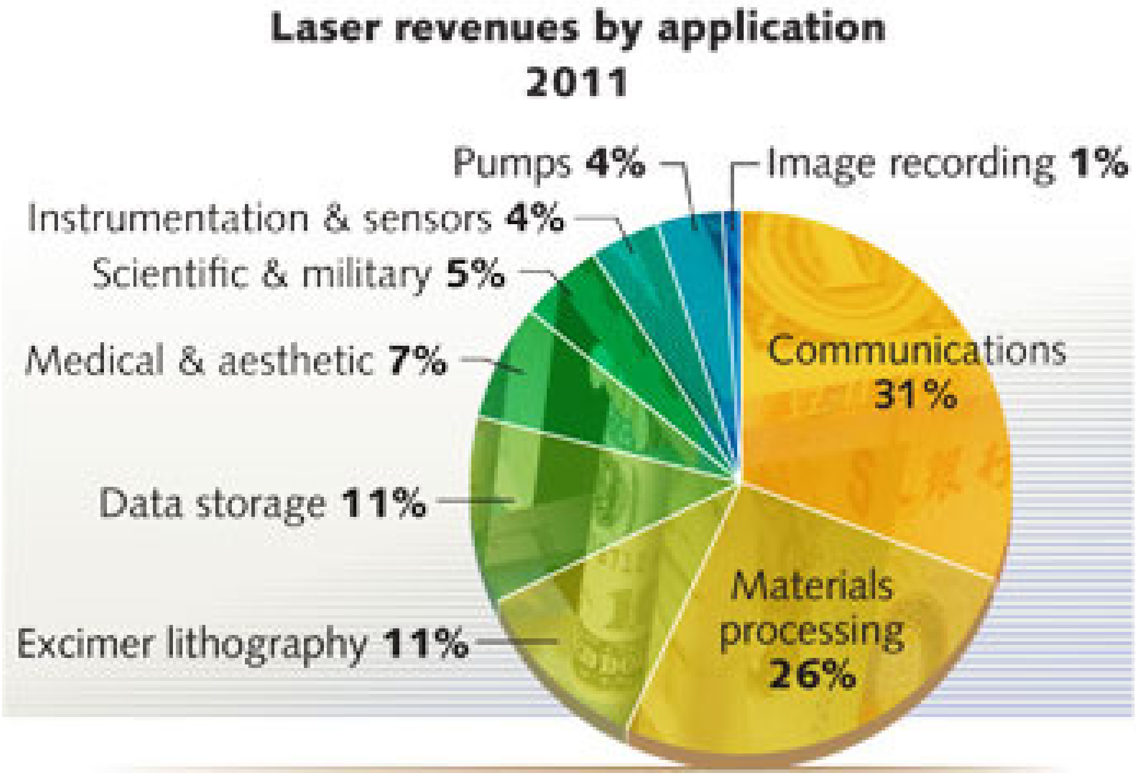
Fiber laser robot cutting system.



A rapid prototyping structure.
Net-shape, high-value tools or metal components can be produced at significantly lower cost and shorter lead times in one-off or small batch production runs.

Fiber Laser Cutting of Stents.
Fiber lasers can produce very low taper high aspect ratio cuts with very little process optimization.

Market



Data Courtesy of Laser Focus Word 2012, Annual Review And Forecast.

Conclusions

Worldwide laser sales reached $7.46 billion dollars in 2011,
growing 14% compared to 2010 — 3% higher than our 11% growth forecast last year.

For 2012, Laser Focus World forecasts laser sales to modestly grow to $7.57 billion.

Industrial laser revenues in 2011 came close to the magic $2 billion level
showing a 19% increase over the previous year.

Carbon-dioxide (14%), solid-state (4%), and fiber laser (48%) sales increases were
joined by a 17% growth in sales of diode and excimer.