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CENTRAS



Picosecond Laser Modification of GIGS Active Layer

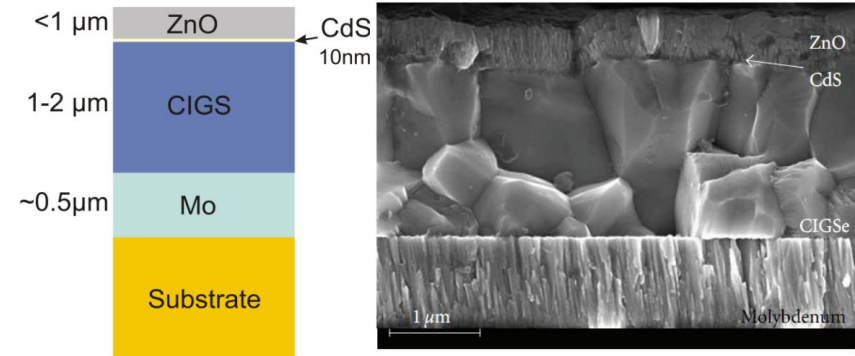
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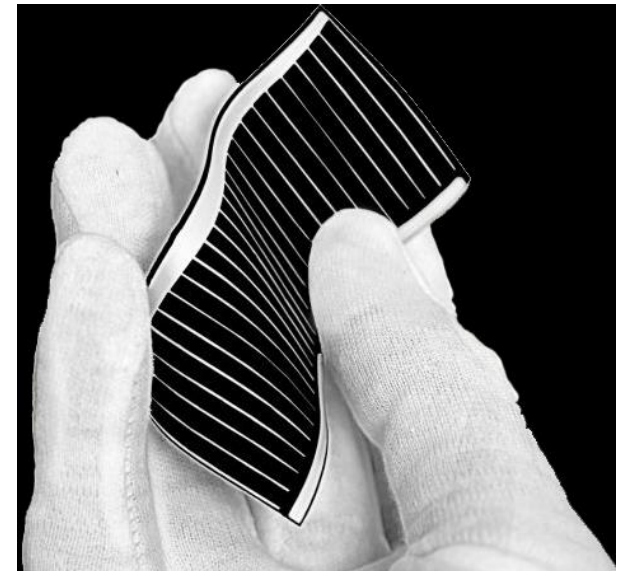
p.gecys@ftmc.lt

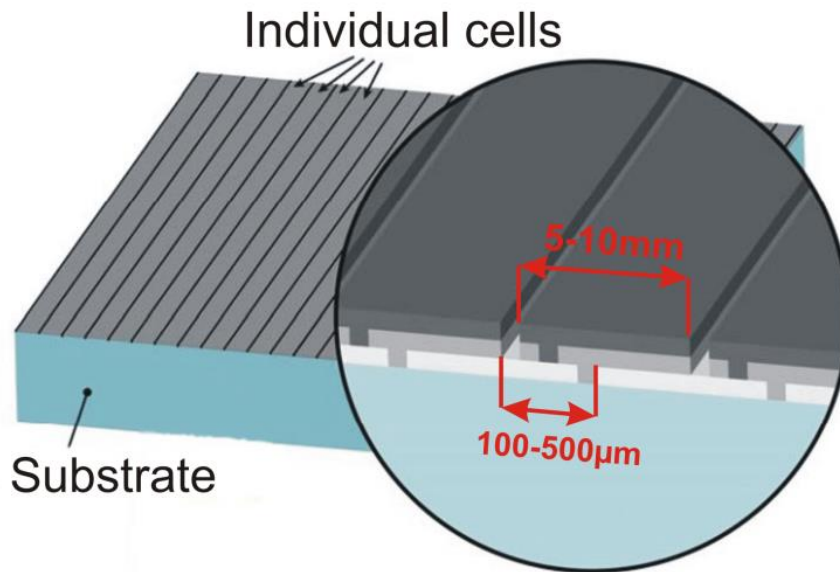
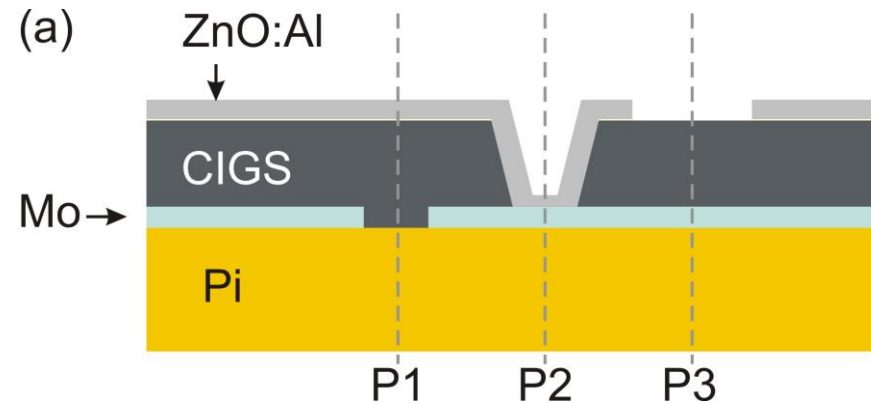
Cu-chalcopyrite based solar cells technologies:

$\text{CuIn}_x\text{Ga}_{1-x}\text{Se}_2$ -(CIGS)



- Save resources (thin layers)
- Low manufacturing cost expected in the future (Roll-to roll process)
- Flexible substrate (easy to integrate)
- Good W_p / weight ration (space applications)
- Performance up to 21.7% (ZSW 2014)





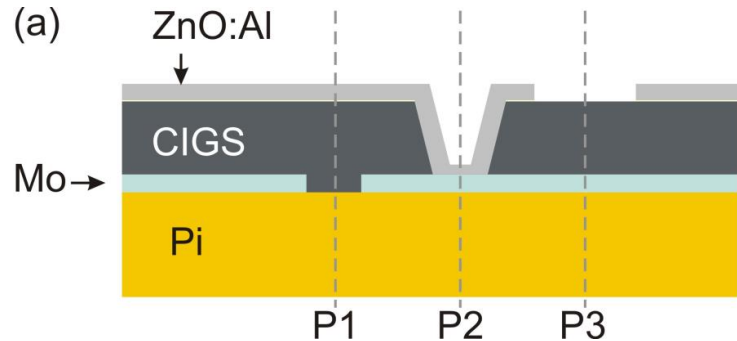
C. Dunskey and F. Colville: Solid state laser applications in photovoltaics manufacturing, Proceedings of SPIE 6871, (2008).

Demands on laser technology

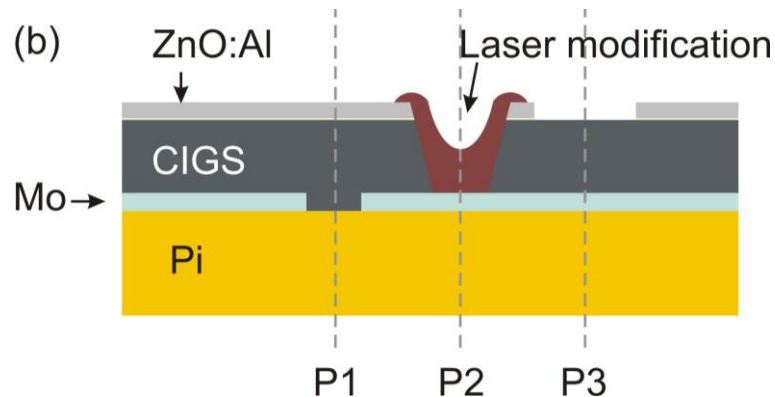
- Layer selectivity
- Fast 1-2m/s scribing
- Reliable

P1- laser scribing
P2, P3- mechanical or laser scribing

P2 process



- Deposition processes have to be interrupted ☹️
- Good AZO-Mo interface based interconnection 😊

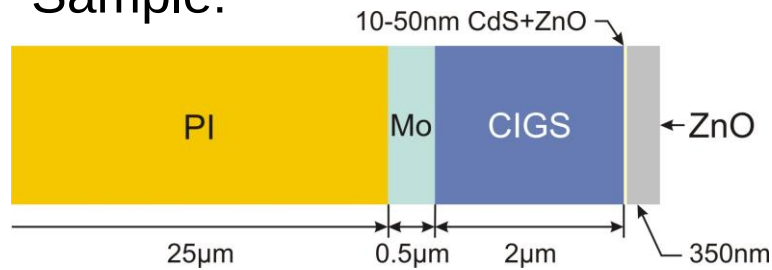


- Post processing 😊
- Single P2 and P3 process step 😊
- P2 interconnection conductance ☹️

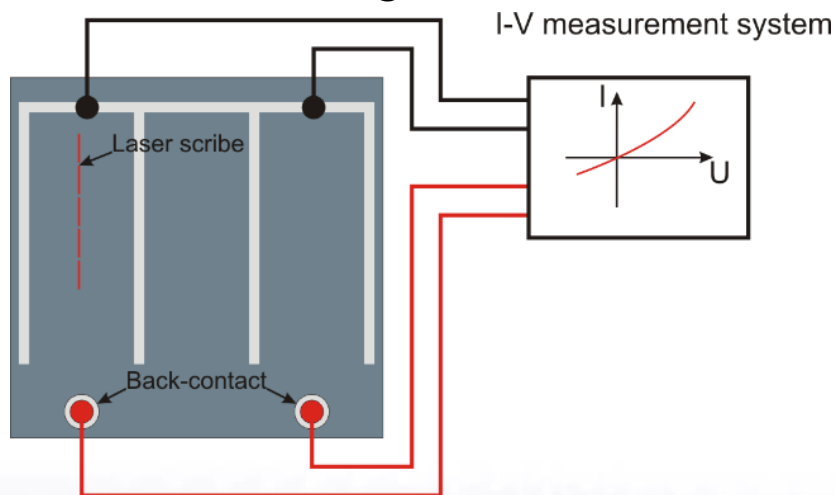
- P2 conductivity of $<1\Omega\text{-cm}$ (10ns) [1] 😊
- Ns and ps lasers are needed for P2 and P3 ☹️

Use of ps laser for P2 welding

Sample:



Electrical testing:

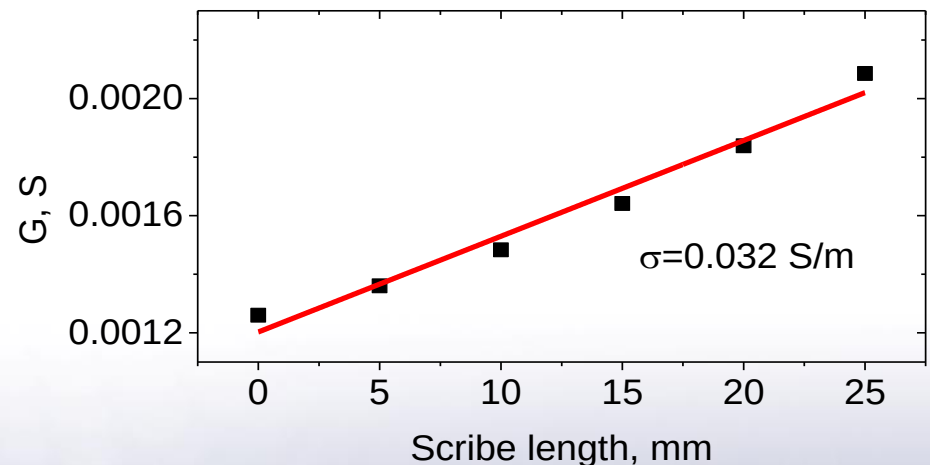


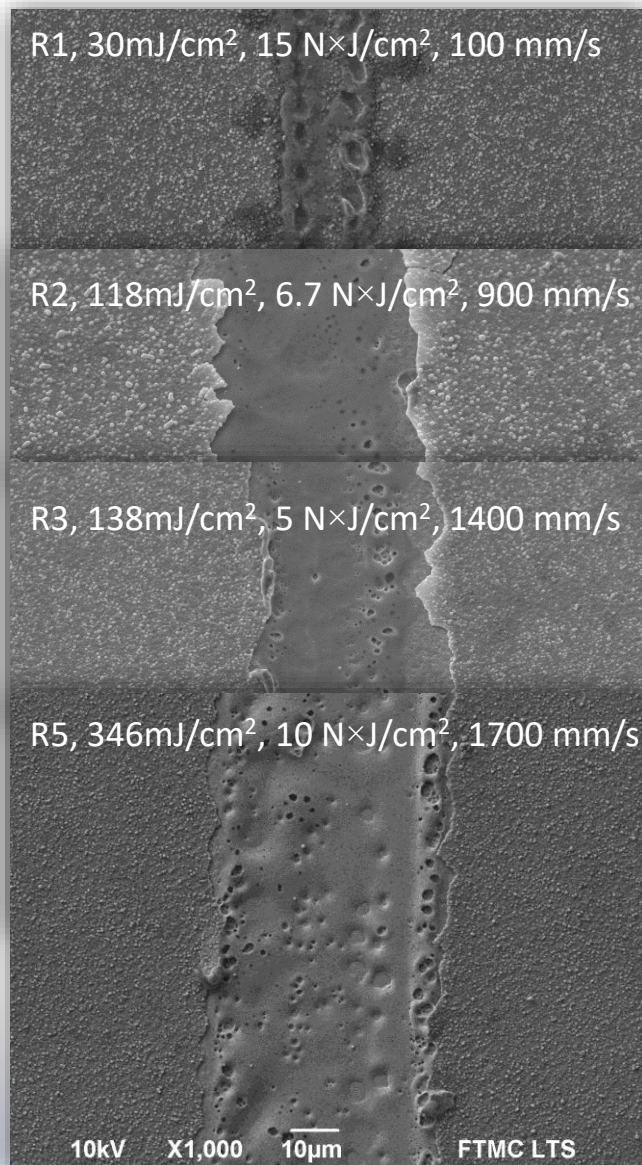
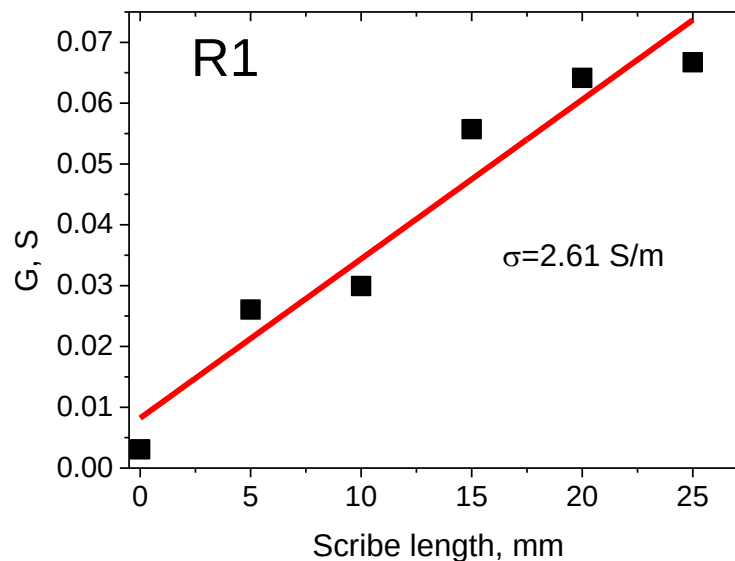
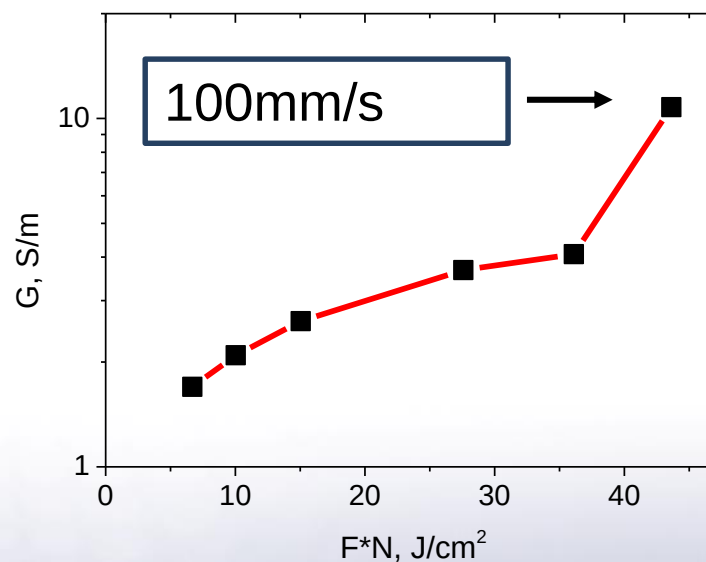
Atlantic series ps laser (EKSLA)
1000kHz, 60W, 13ps, 532nm

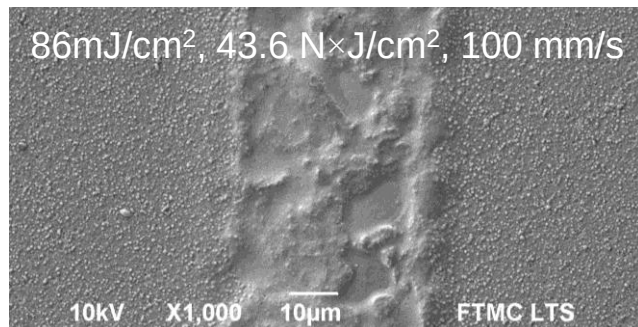
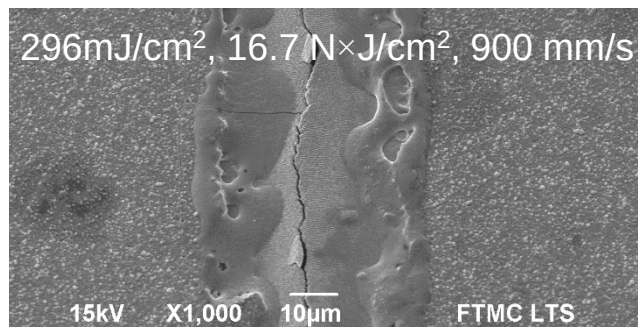
**Scanner from ScanLab with
+80mm objective**

Additional P2 testing:

- **SEM+EDS**
- **Raman**

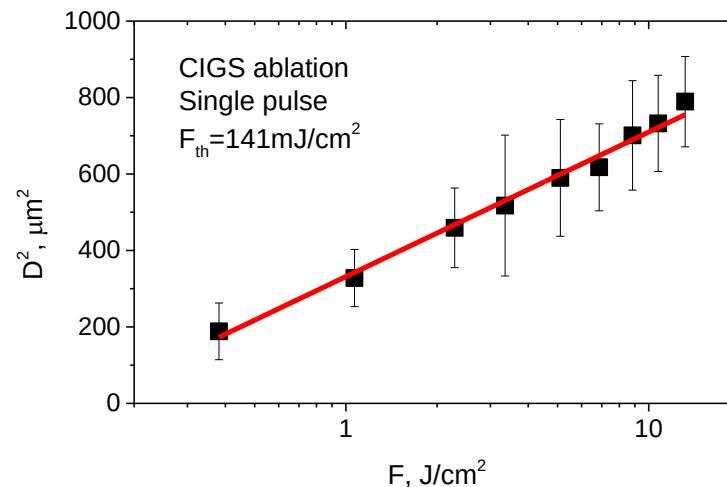
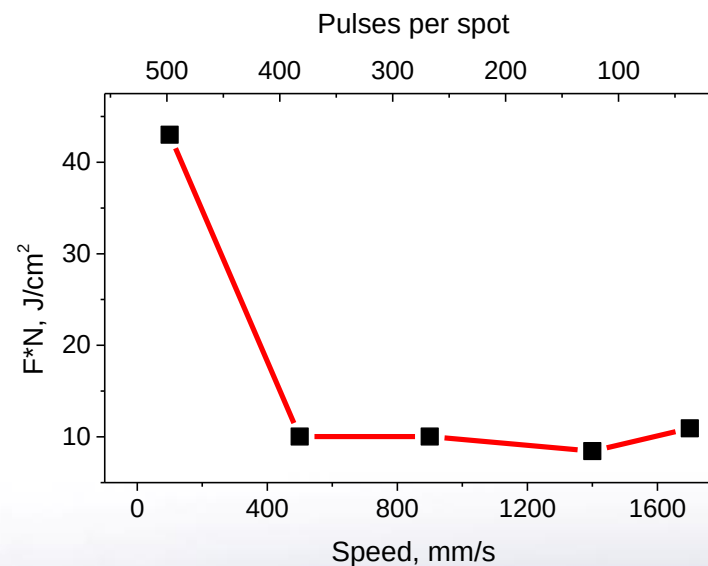


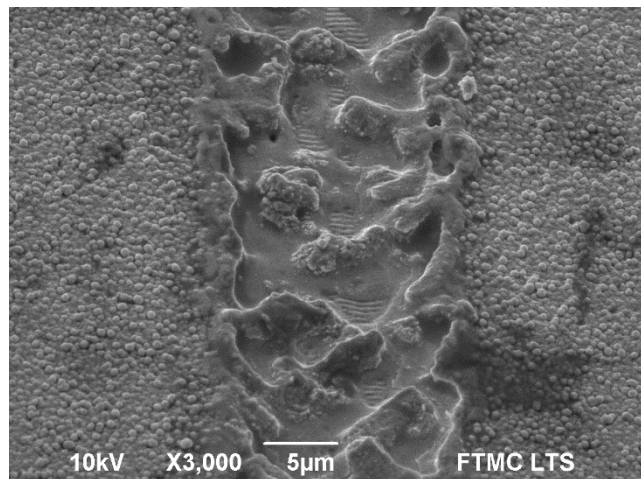




CIGS modification:

- Irradiation with $F < F_{th}$
- High pulse overlap



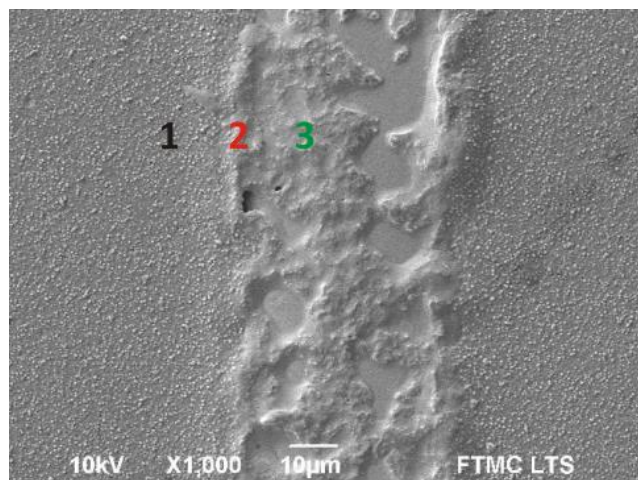


Sample	P2 cond., S/m	P2 res., Ω -cm	P2 res., Ω -cm ²
1	21.96	4.55	0.0091
2	17.24	5.80	0.0116
5	15.93	6.28	0.0126
6	13.84	7.22	0.0144
7	10.09	9.91	0.0198
9	18.25	5.48	0.0110
10	28.31	3.53	0.0071
Average:		6.11	0.0122

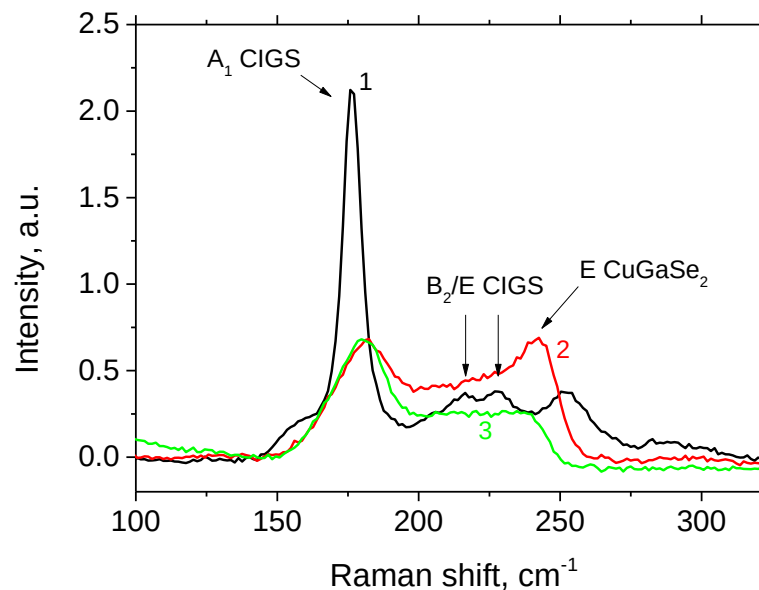
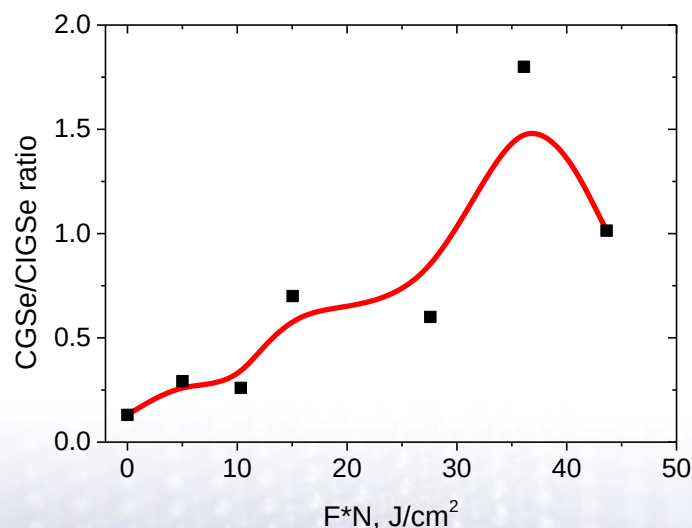
76mJ/cm², 100 mm/s

Scribe width, μ m	G, S/m	R, Ω -cm	R, Ω -cm ²	P2 process type	Source
50	6.67	15	0.075	welding	S. Pellegrino et al.
50	100	1	0.005	welding	
50	163	0.61	0.00305	AZO-Mo	Kessler et al.
50	909	0.11	0.00055	AZO-Mo	
50	100	1	0.005	Commercial module AZO-Mo	Ju-Heon Yoon et al.
50	250	0.4	0.002	Welding	Westin et al.
50	100	1	0.005	AZO-Mo	J. Ermer et al.
50	100	1	0.005	AZO-Mo	J. Johansson et al.

Target P2 conductivity 1 Ω -cm or 0.005 Ω -cm²

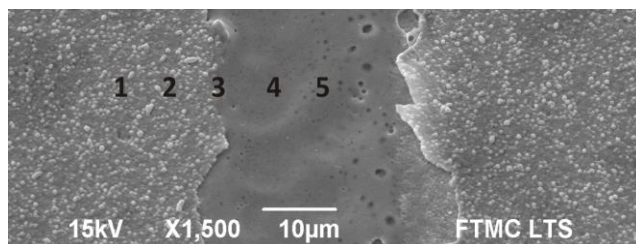


86mJ/cm², 43.6 N×J/cm², 100 mm/s

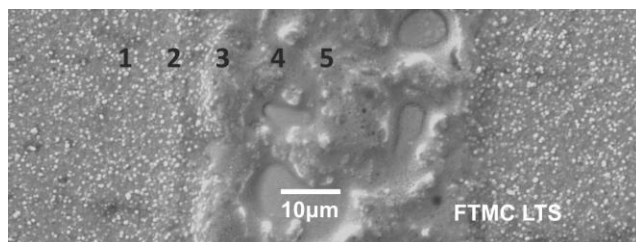


CuGaSe₂ resistivity ~1 Ω-cm [1]
CIGS resistivity ~50 Ω-cm [1,2]

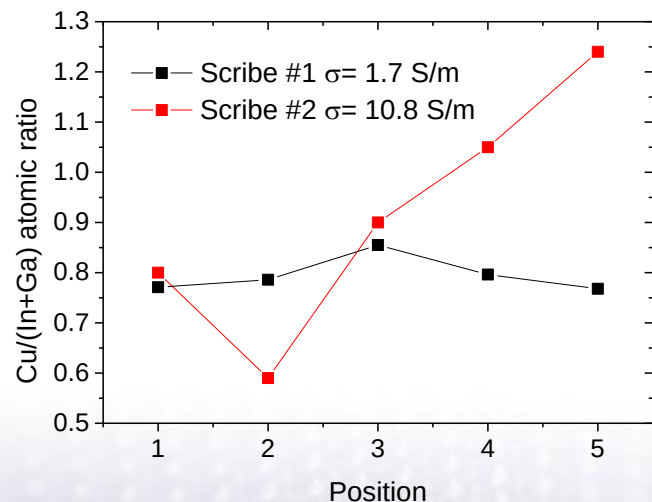
- [1] S. R. Kodigala, "Electrical Properties of I-III-VI₂ Compounds, in Thin Films and Nanostructures", ed. by S.R. Kodigala, (Publisher, Academic Press, Amsterdam 2010). p. 319.
[2] Y.-m. Xue, B.-h. Yang, C.-q. Qu, L. Zhang, C.-m. Xu and Y. Sun: Optoelectron. Lett., 4, (2008) 437.



R2, 118mJ/cm², 6.7 N×J/cm², 900 mm/s



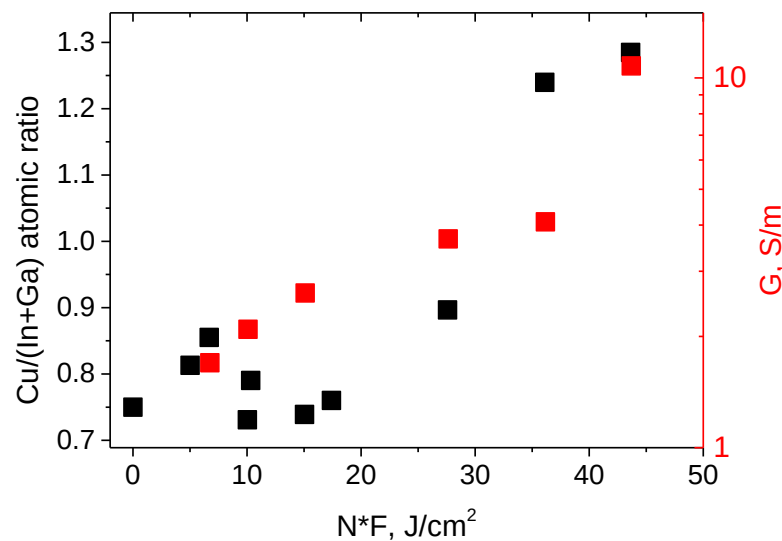
86mJ/cm², 43.6 N×J/cm², 100 mm/s



CIGS

$\text{Cu}/(\text{In}+\text{Ga}) = 0.76$ $\sim 50 \Omega\text{-cm}$ [1]

$\text{Cu}/(\text{In}+\text{Ga}) = 1.2$ $0.01\text{-}1 \Omega\text{-cm}$ [1,2]



[1] Y.-m. Xue, B.-h. Yang, C.-q. Qu, L. Zhang, C.-m. Xu and Y. Sun: Optoelectron. Lett., 4, (2008) 437.

[2] S. H. Kwon, D. Y. Lee and B. T. Ahn: J. Korean Phys. Soc., 39, (2001) 655.

- Picosecond laser scribing can be used for P2 welding process.
- Use of $F < F_{th}$ and high pulse overlap resulted in high conducting properties of the P2 micro-weld area.
- The scribe specific conductivity tend to increase with increasing laser irradiation dose.
- The average 6.1 Ω -cm scribe resistivity was obtained with ps pulses.
- Formation of Cu-rich CIGS and CGSe phases in the laser processed P2 scribe channel resulted in significant changes of the material electrical conductivity.

Thank you

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