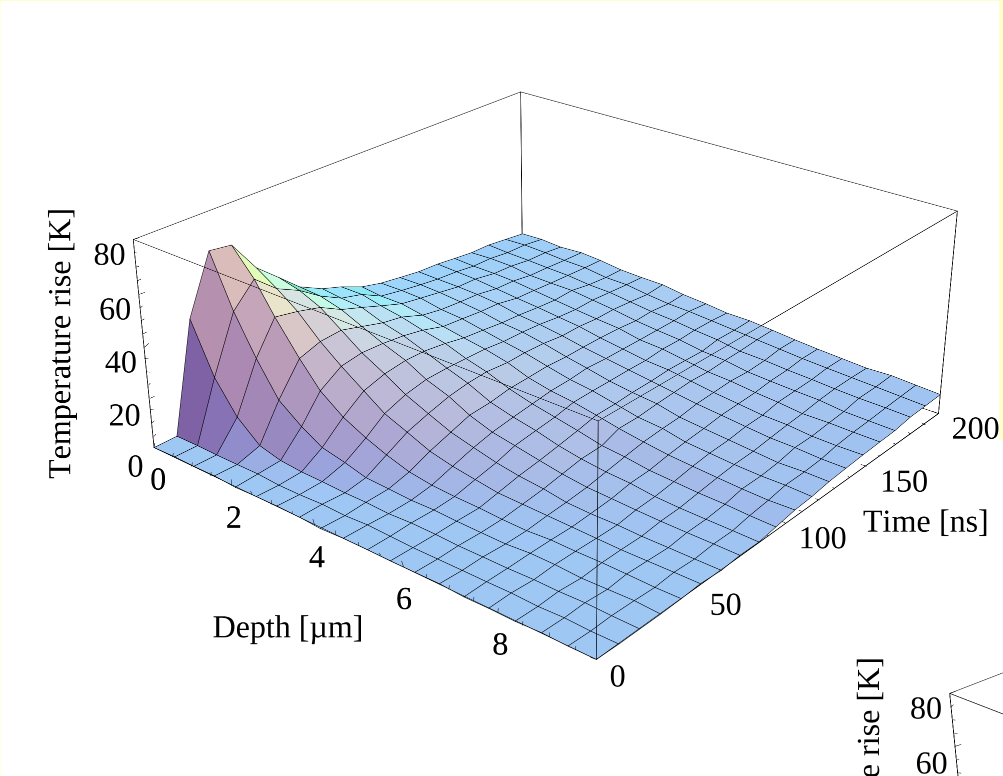
Fatigue studies for CLIC: laser testing

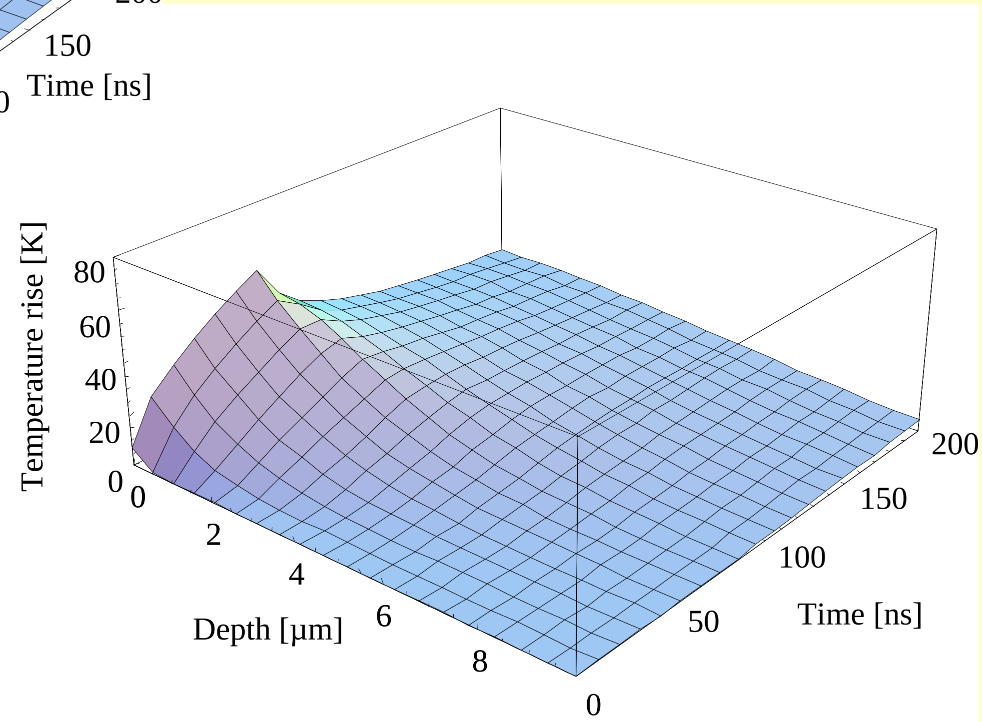
- Several questions needed to be answered:
  1. Are laser studies relevant for RF applications?
  2. Can the “low-cycle” laser fatigue studies be connected with the “high-cycle” ultrasound fatigue studies?
  3. What is the best candidate material selected with these studies?

Comparison of heating profiles



← Laser pulse

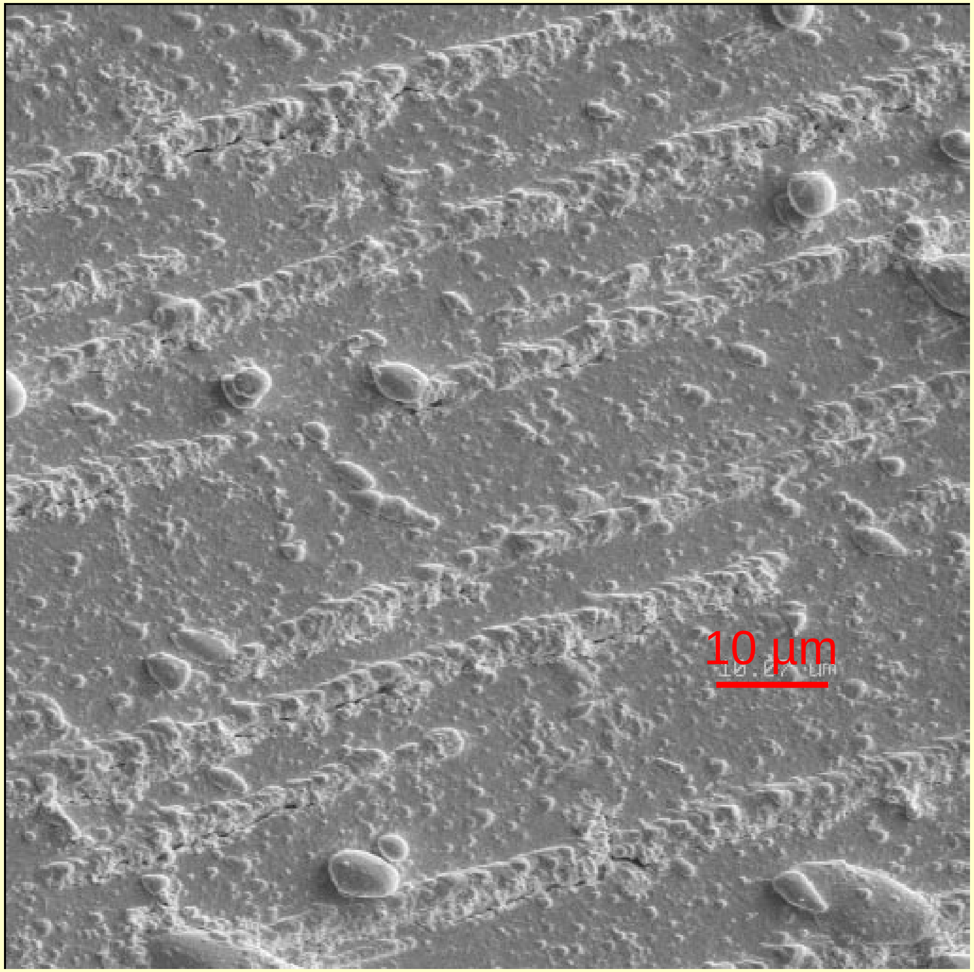
RF pulse ↓



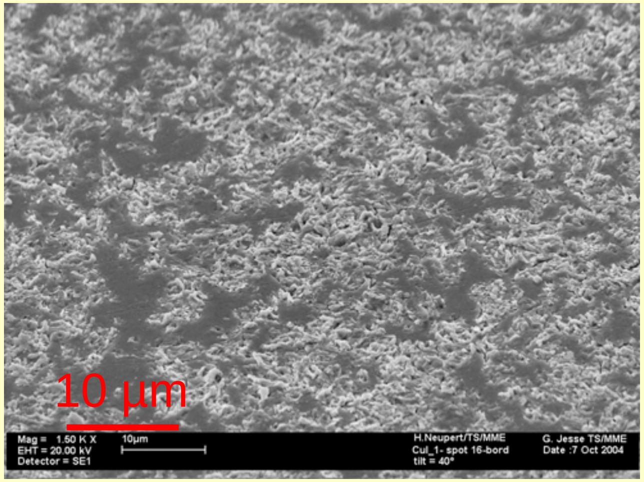
The pulse shapes correspond.
In particular the temperature profile at the peak is very similar, and results in similar stress level.

$$\sigma = \frac{\Delta T * E * \lambda}{(1-\nu)}$$

Comparison of surface damage: RF & laser



Cu, 56 Mpulses, ΔT = 120 K, σ = 170 MPa
[D.P. Pritzkau and R.H. Siemann, PRST-AB **5**, 112002 (2002)]



Cu, 1 Mshots, 0.1 J/cm^2,
ΔT = 80K, σ = 115 MPa

There is only one known RF experiment that allows comparing RF-induced surface damage and laser-induced surface damage.
It seems logical to assume that the physical mechanisms behind fatigue are the same in both cases

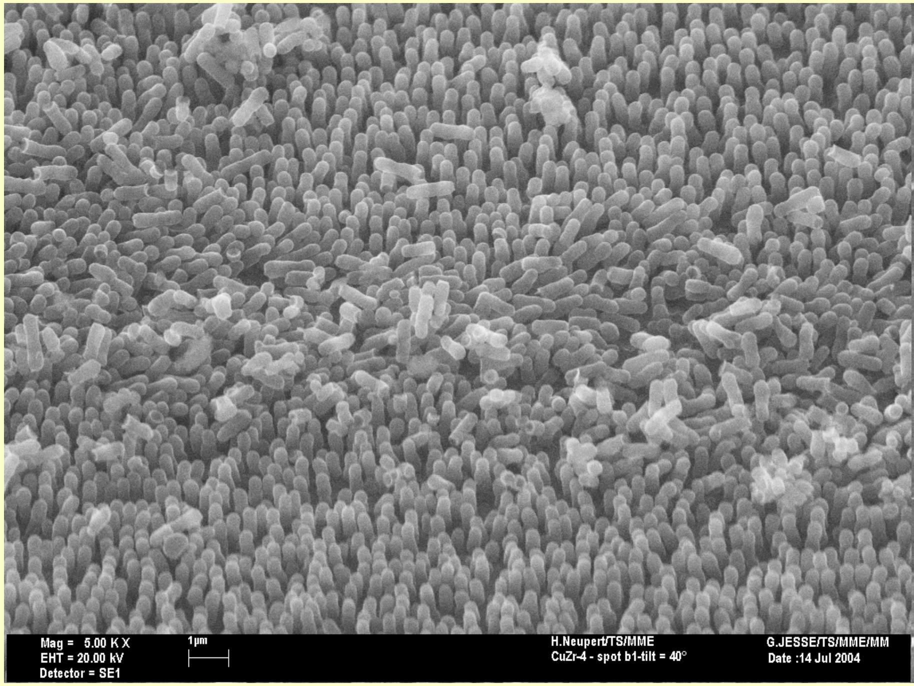
Comparison of surface damage

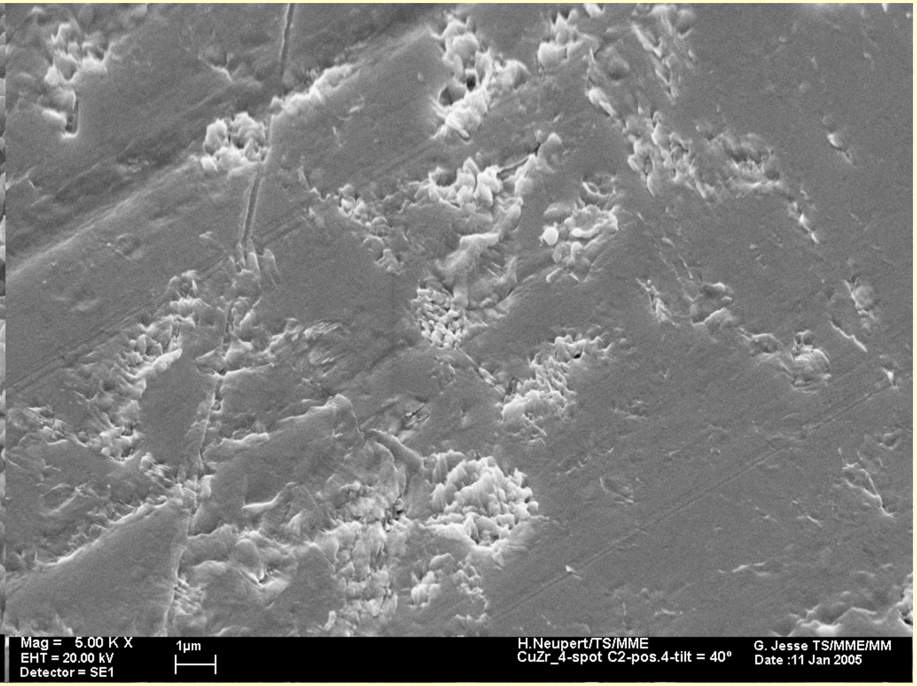
1. Are laser tests relevant for RF applications?

Yes, up to our best knowledge. No further RF data are available at present (Dubna data are still insufficient)

2. Can the “low-cycle” laser fatigue studies be connected with the “high-cycle” ultrasound fatigue studies?

Surface damage: 10^7 cycles in bad and good vacuum



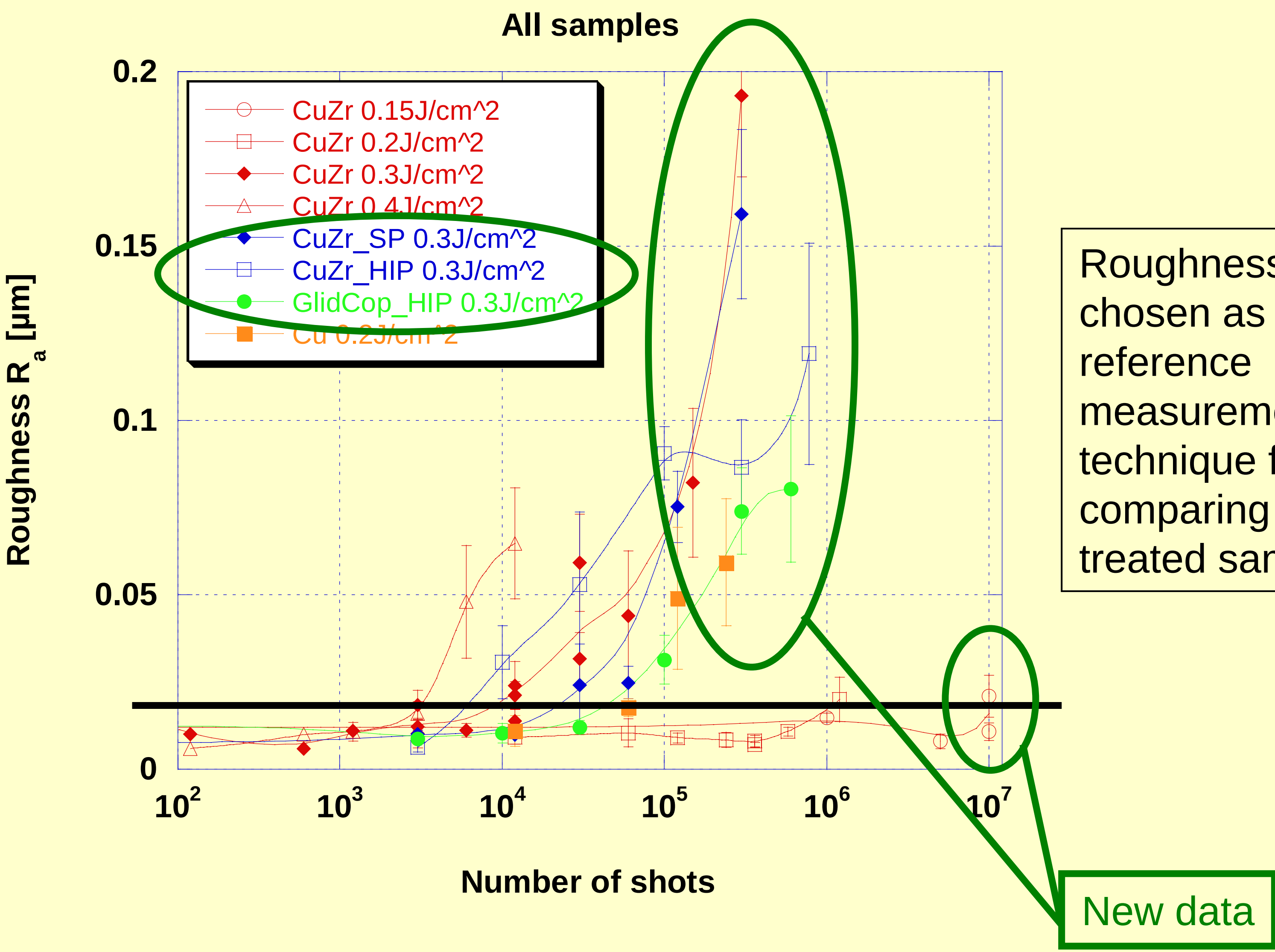


CuZr, 10 Mshots, 0.15 J/cm^2, ΔT = 120 K, σ = 170 MPa, under bad vacuum (oil vapors contamination?)

CuZr, 10 Mshots, 0.15 J/cm^2, ΔT = 120 K, σ = 170 MPa, under clean vacuum (turbopump)

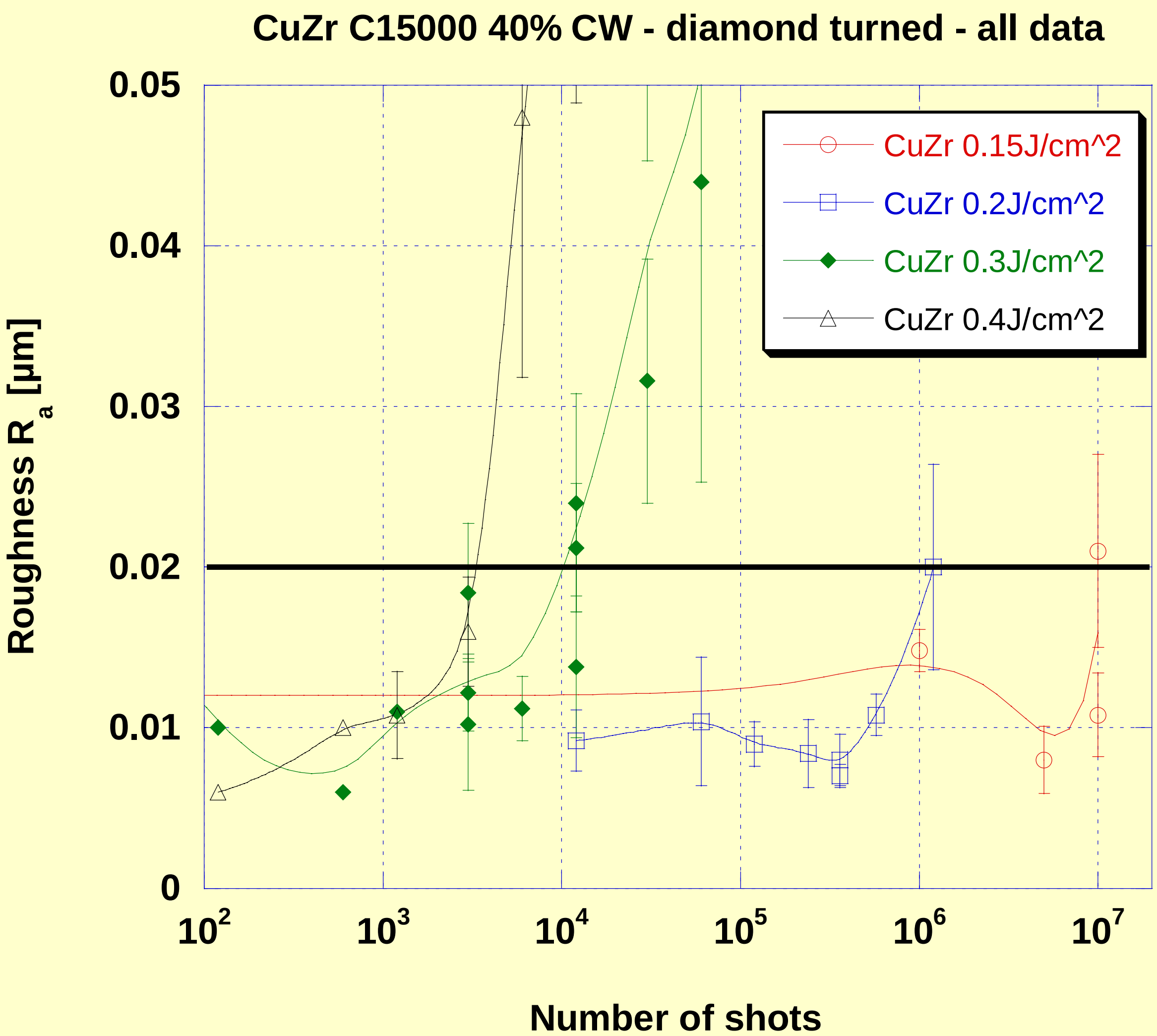
This is shown in order to confirm that vacuum is important. All new tests have been done in good vacuum. There is probably no need to go through all the SEM pictures

Surface roughness as a function of fluence and number of shots



Roughness has been chosen as the reference measurement technique for comparing laser treated samples

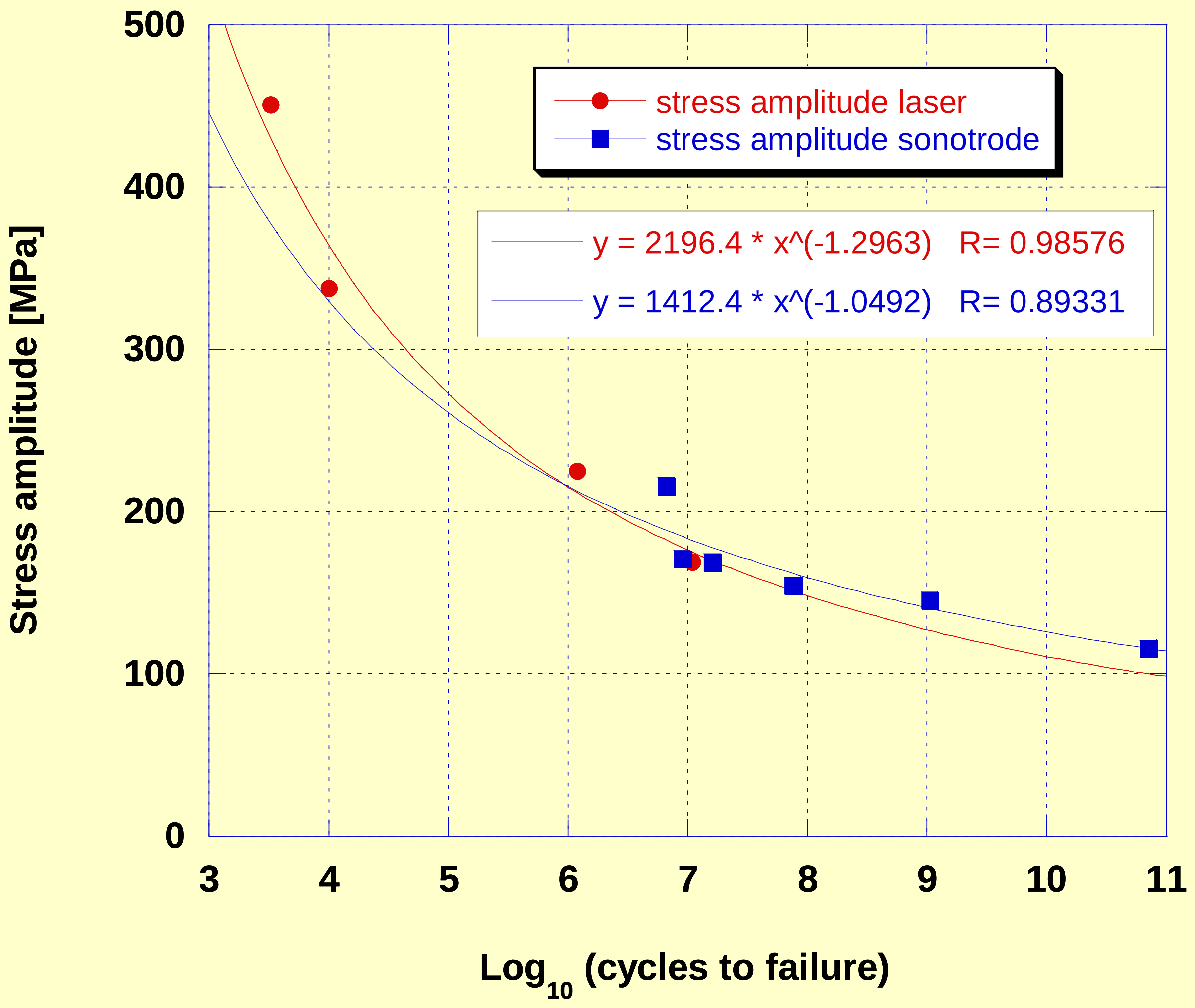
Surface roughness as a function of fluence and number of shots: CuZr



The value of 0.02 µm has been chosen as the first measurable departure from the reference surface (flat, diamond turned).

This is thought being the most important phenomenon. The further increase of roughness is only crack propagation.

Fatigue limit: laser & ultrasound



Fatigue: laser & US prediction capabilities

2. Can the “low-cycle” laser fatigue studies be connected with the “high-cycle” ultrasound fatigue studies?

Yes. More data are needed at the same number of cycles with the two techniques in order to improve the prediction capabilities.
More data ⇒ better uncertainties
In particular laser data at up to 10^8 cycles must be obtained (new laser)

3. What is the best candidate material selected with these studies?

Possible material candidates

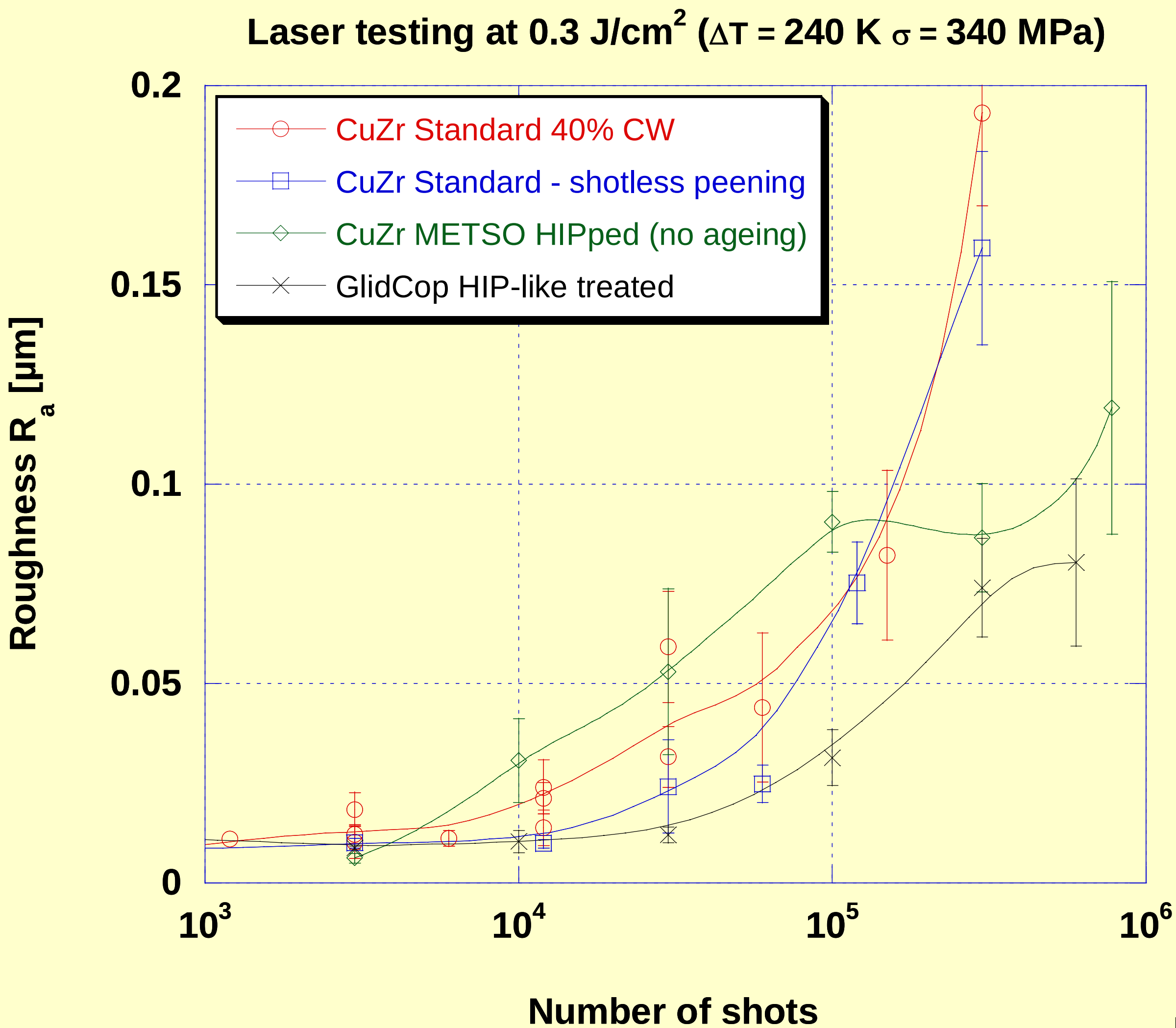
	Cu-OFE C10100	CuZr C15000	Glidcop-AL15 C15715	Glidcop-AL25 C15725	Glidcop-AL60 C15760	Mo	W	Al	Ti	Au
Power dissipation relative to Cu	1	1.05	1.05	1.08	1.14	1.83	1.78	1.26	5.64	1.14
ΔT relative to copper for a given pulse duration	1	1.10	1.09	1.16	1.27	3.61	3.16	1.95	29.12	1.50
Maximum stress during pulse compared to copper	1	1.18	1.20	1.28	1.40	3.06	2.99	1.66	15.91	0.85
Yield strength σ0.2 (annealed) [MPa]	55	80	255	296	331	450	550	20	140	1.7
Safe elastic limit = 70% yield strength (annealed) [MPa]	39	56	179	207	232	315	385	14	98	1
Pulse length in order to remain below safe elastic limit [ns]	4.6	7	68	**81**	84	33	51	0.2	0.1	0.0
ΔT with this pulse length [K]	12	17	51	60	67	118	129	5	57	1

Several states of CuZr have also been investigated:

- CuZr C15000 « standard » (aged 40% cold worked)
- Same with « shotless peening treatment »
- CuZr made by METSO (bi-metal bar) HIPped, solution annealed (no ageing)

All samples are diamond turned. This induces a pre-stress on the surface. The shotless peened sample has an even higher pre-stress

CuZr: effect of metallurgical state



For a given material (CuZr) in different states, smaller grain size and higher strength results in higher "fatigue crack initiation resistance" but also higher "fatigue crack growth speed“ (to be confirmed by further literature search)

Please note the error bars

Fatigue: laser & US prediction capabilities

3. What is the best candidate material selected with these studies?

Unfortunately a lot more data is needed. Data available now allow to say:

- CuZr treated in its best metallurgical state is a good candidate
- Glidcop is an even better candidate (only one point available!)
- CuCrZr… Samuli will talk about it, and definitely needs testing

We have reached the stage where the basic work has been done, and now a lot of statistics is needed.

$\Rightarrow$ We would need a CERN Fellow dedicated to this work