PMMA-Ablation for characterization of focused XUV radiation beams

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Outline

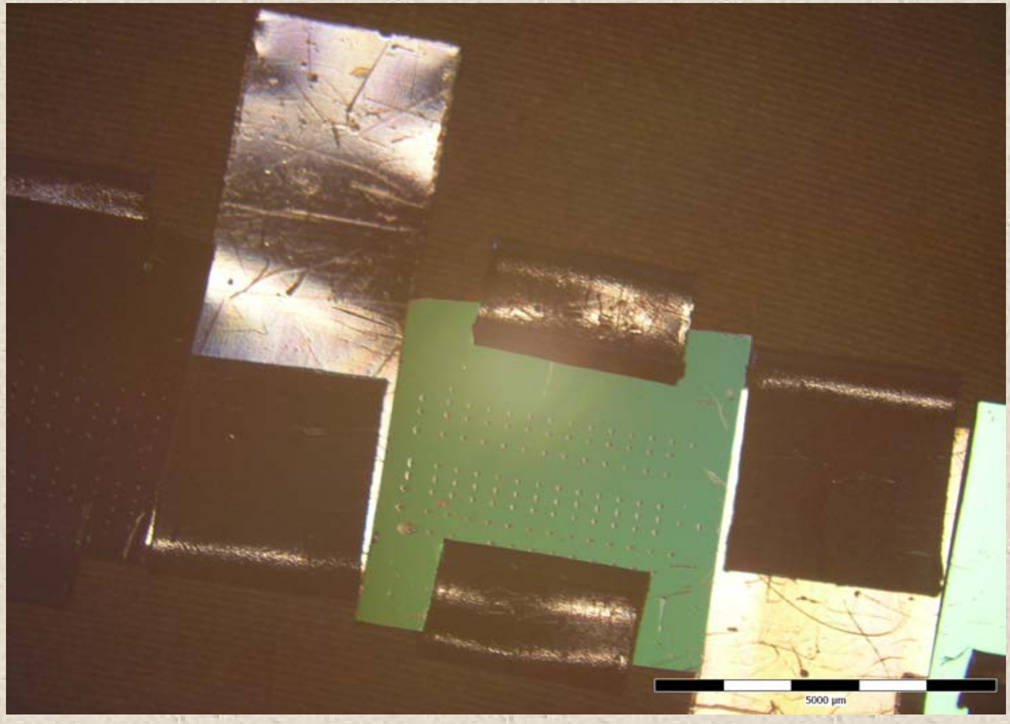
- *Investigated samples, „post-mortem“ samples analysis, and irradiation conditions*
- *Generalised Liu's model of PMMA ablation induced by XUV/soft X-Ray free-electron laser radiation*
- *Data analysis*
  - *Crater depth, area, volume analysis*
  - *Deposited energy density*
- *Future PMMA perspectives*

Samples of organic solids and analysis

- *500 nm thin layer of PMMA - poly (methyl methacrylate); spin coated on 315 µm thick Si substrate, Silson (UK)*

- *massive samples of PMMA, Goodfellow (UK)*

- *"post mortem" analysis*
  - *Nomarski (DIC – differential interference contrast) microscope*
  - *atomic force microscope (AFM)*



PMMA (thin layer) sample placed in a sample holder (picture taken by V.Hájková)

Irradiation conditions

FLASH - <u>F</u>ree Electron <u>LAS</u>er in <u>H</u>amburg (DESY)

- *used wavelength:* ***32nm***
- *average pulse duration and energy:* ***~ 30fs, ~10µJ***
- *peak power ranges from* ***~100MW*** *up to* ***~1GW***
- *repetition rate:* ***2Hz****.*
- *expected beam diameter at sample surface:* ***20µm****.*
- *normal incidence, tight focus, single shot exposure in ultra-high vacuum*
- *pulse energy varied by a gas attenuator*

Generalised Liu's[1] model

- *Main assumptions*
  - interaction linearity
  - *common spatial and temporal intensity profile*

$$I\left(\vec{r},t\right)=I_0\cdot f\left(\vec{r}\right)g\left(t\right)$$

  - *ultra-short pulse duration decreases the efficiency of slow thermal effects → sudden response assumption*
  - *SVEA (slowly varying envelope approximation) in direction of beam propagation*

$$\left|\frac{\partial f\left(x,y,z\right)}{\partial z}\right| \ll \left|l_{at}^{-1} f\left(x,y,z\right)\right|$$

[1]J. M. Liu: Simple technique for measurements of pulsed Gaussian-beam spot sizes, *Opt. Lett.* **7**, 196-198 (1982)

- *Beam profile and crater shape*

  – *transversal beam distribution on sample surface may be expressed in terms of known attenuation lentgh l_{at}, ablation threshold F_{th},and measured crater profile d(x,y) as follows*

$$F(x,y,0) = F_0 f(x,y,0) = F_{th} \exp\left(d(x,y)/l_{at}\right)$$

  – *on the other hand, the crater profile is given by the fluence distribution*

$$d(x,y) = l_{at} \ln\left(\frac{F_0}{F_{th}} f(x,y,0)\right)$$

- *Global deposited energy density*
  - *3-dimensional AFM pictures allow us to express global deposited energy density*

$$\varepsilon = \frac{E_{deposited}}{V} = F_{th} \frac{\int\limits_{\substack{crater\\area}} \left[\exp\left(d\left(x,y\right)/l_{at}\right)-1\right] dxdy}{\int\limits_{\substack{crater\\area}} d\left(x,y\right) dxdy}$$

Data analysis

Assuming a Gaussian beam profile, craters should have a parabolic shape.

$$d(r) = l_{at}\left(\ln\left(\frac{E_{pulse}}{E_{th}}\right) - \frac{S}{S_{foc}}\right),\ S = \pi r^2,\ S_{foc} = \pi\rho^2$$

Crater depth

$$d = l_{at}\ln\left(E_{pulse}/E_{th}\right)$$

Crater volume

$$V = \frac{1}{2}S_{foc}l_{at}\ln^2\left(E_{pulse}/E_{th}\right)$$

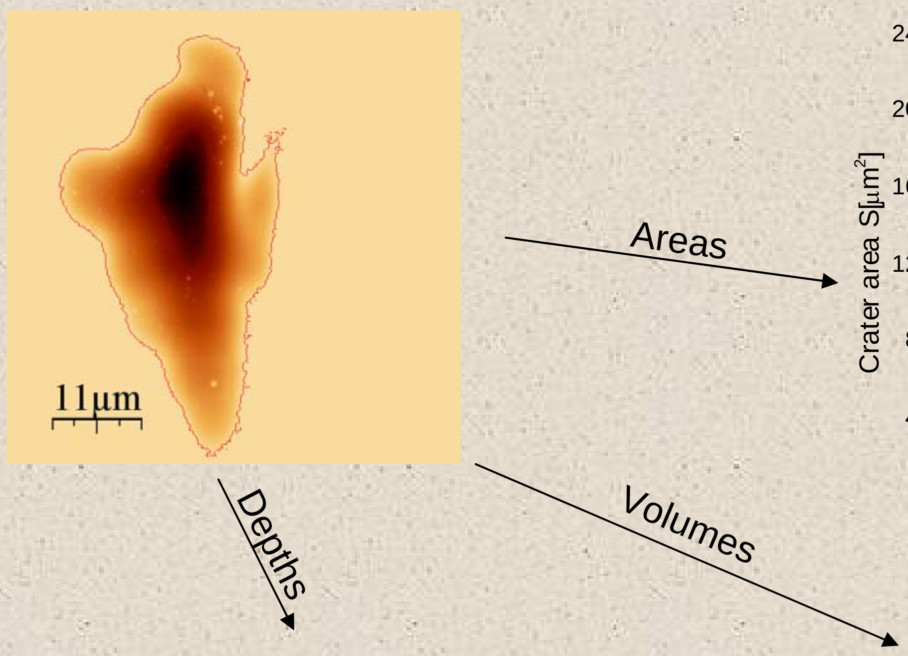
Crater area

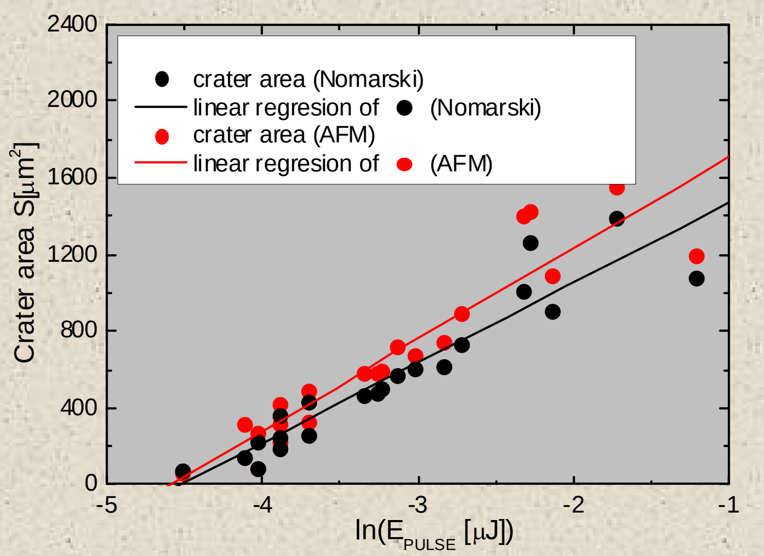
$$S = S_{foc}\ln\left(E_{pulse}/E_{th}\right)$$

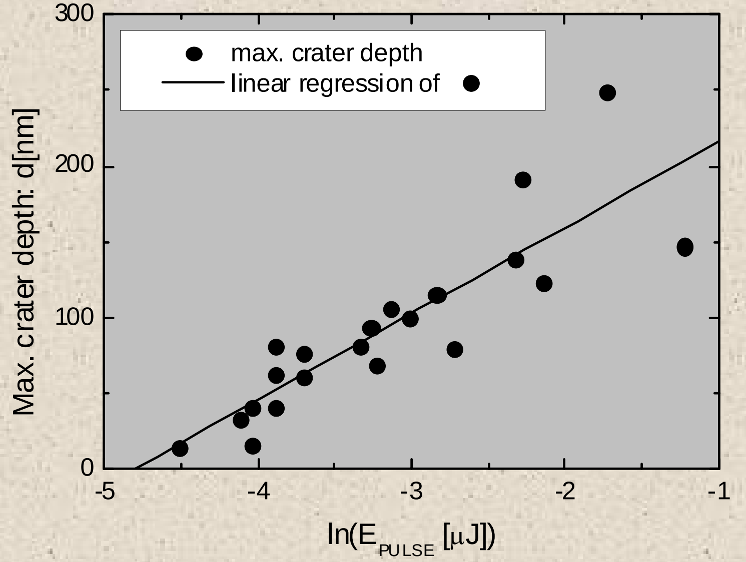
Global deposited energy density

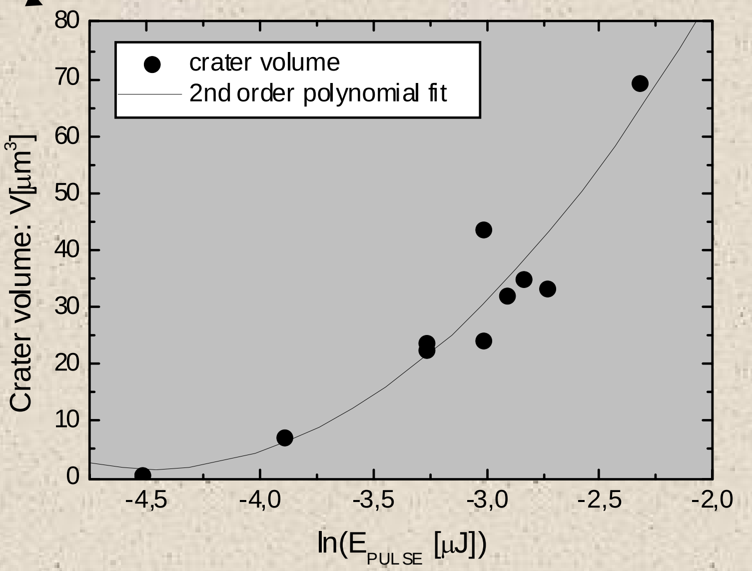
$$\varepsilon \approx \frac{E_{pulse}/E_{th} - \ln\left(E_{pulse}/E_{th}\right) - 1}{l_{at}\ln^2\left(E_{pulse}/E_{th}\right)}$$

Crater depth,area, and volume analysis







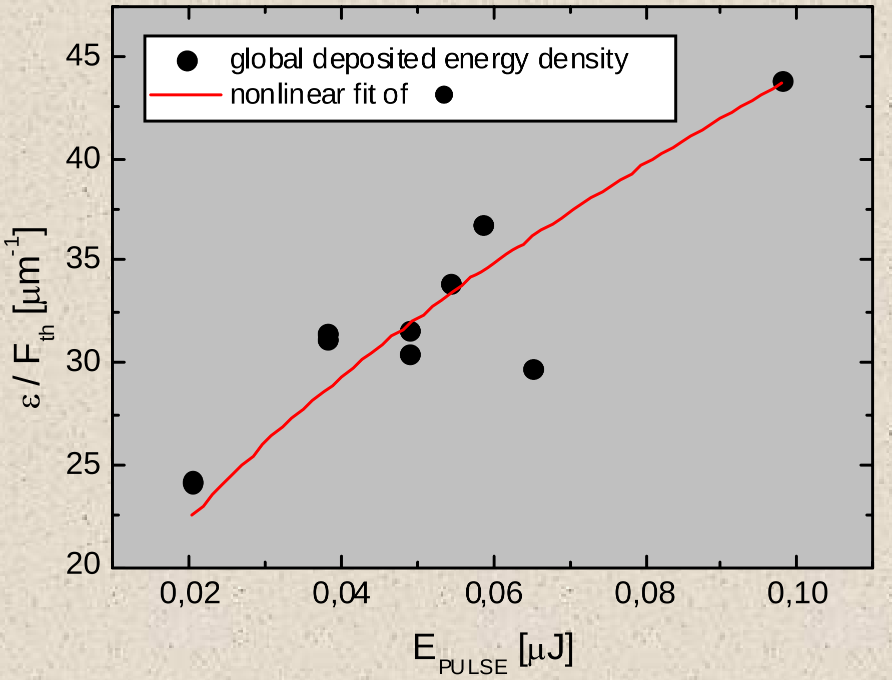


Results

ablation feature evaluated	microscope	ablation threshold F_{th} [mJ/cm^2]	attenuation length l_{at} [nm]	focal spot diameter 2ρ [μm]
crater depth	AFM	(1.8 ± 1.4)	(56.9 ± 7.5)	---
crater area	DIC	(2.6 ± 1.2)	---	(23.0 ± 0.5)
	AFM	(2.1 ± 1.1)	---	(24.6 ± 0.6)
crater volume	AFM	(2.3 ± 2.5)	---	---

Global deposited energy density

- *From AFM pictures we are able to estimate a value, proportional to the global deposited energy density. Measured values correspond well to teoretical prediction.*

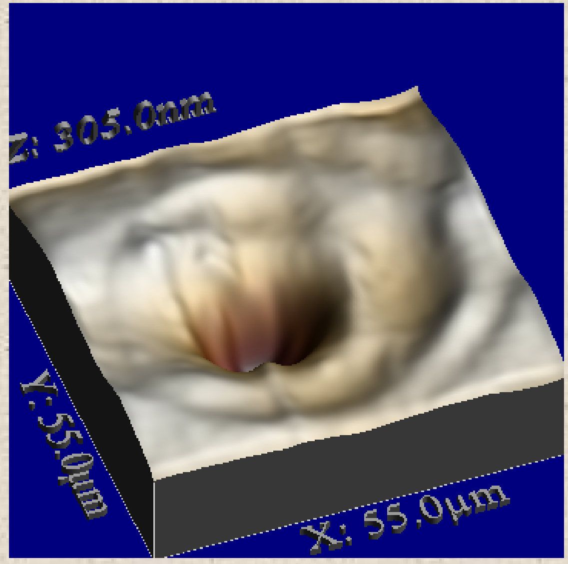


$$\longrightarrow \quad l_{at} = (57.3 \pm 1.7)\, nm$$

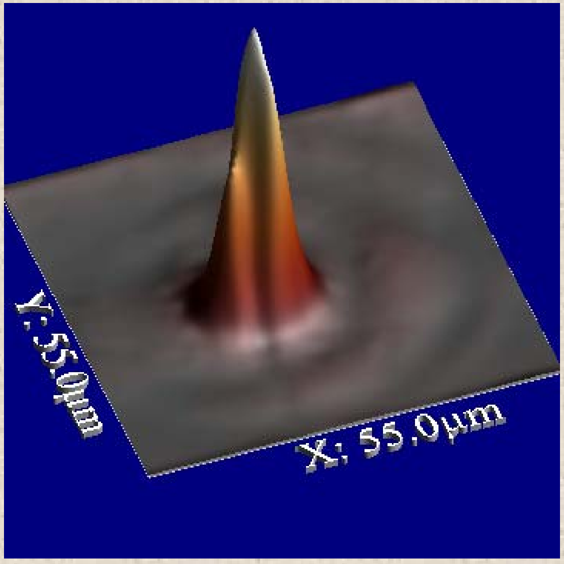
Future PMMA perspectives

PMMA ablation is very clean without thermal damages. Therefore the crater shapes, measured by AFM, allow us to reconstruct beam profile down to the limiting threshold fluence of ~2mJ/cm^2 (at 32nm). Next figures show FLASH's transversal fluence distribution, modulated by difraction.

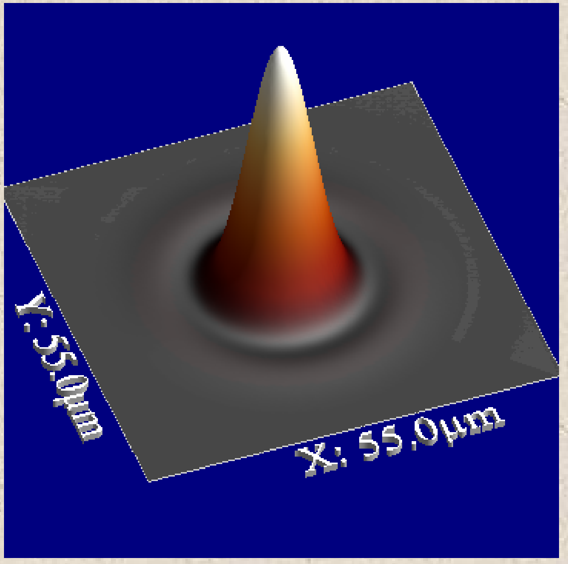
PMMA imprint



Reconstructed field distribution



Modelled field distribution



Conclusions

- PMMA ablation threshold lies at around 2mJ/cm^2 and it's attenuation length (56.9±7.5)nm
- FLASH's focal spot dimeter in tight focus is 2 ρ =(23.8 ± 0.6) μ m. Full width at half maximum is equal to (19.9 ± 0.5) μ m
- FLASH's beam has got more or less Gaussian profile.
- PMMA is a suitable material for beam profile imaging.