Tailored sample designs for ultrafast electron diffraction at high repetition rates

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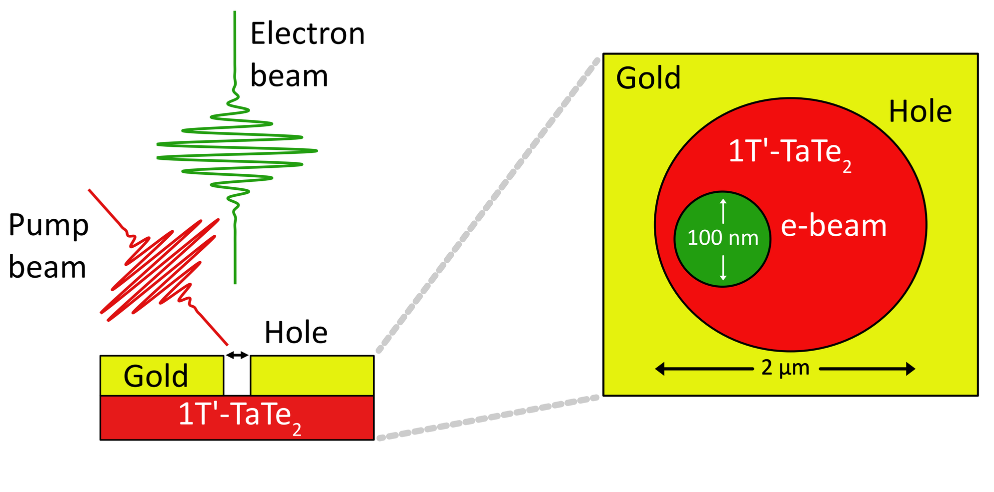
Motivation

- **U**ltrafast **E**lectron **D**iffraction (UED) [1] is a powerful technique to resolve structural dynamics in strongly correlated materials.
- The Göttingen **U**ltrafast **T**ransmission **E**lectron **M**icroscope (UTEM) [2] provides **nanometric** e-beam diameters, which give access to nanoscale heterogeneity that can impact the dynamics [3][4].
- The diffraction signal critically depends on the available duty cycle.
- A critical complication arises from the **cumulative heating** of the sample at high repetition rates.

- Create a sample design tailored to
  1) Confine the laser exitation volume
  2) Efficiently dissipate the thermal load

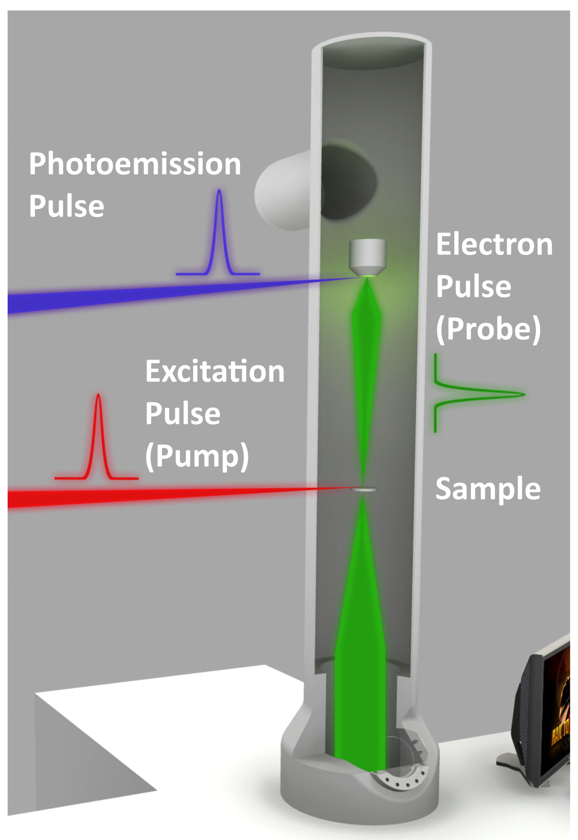
Experimental Setup

Sample excitation in time-resolved UED experiment



Pump beam excitation of the sample and subsequent electron beam probing

Samples top view where crystal lies under gold mask and electrons probe a specific region

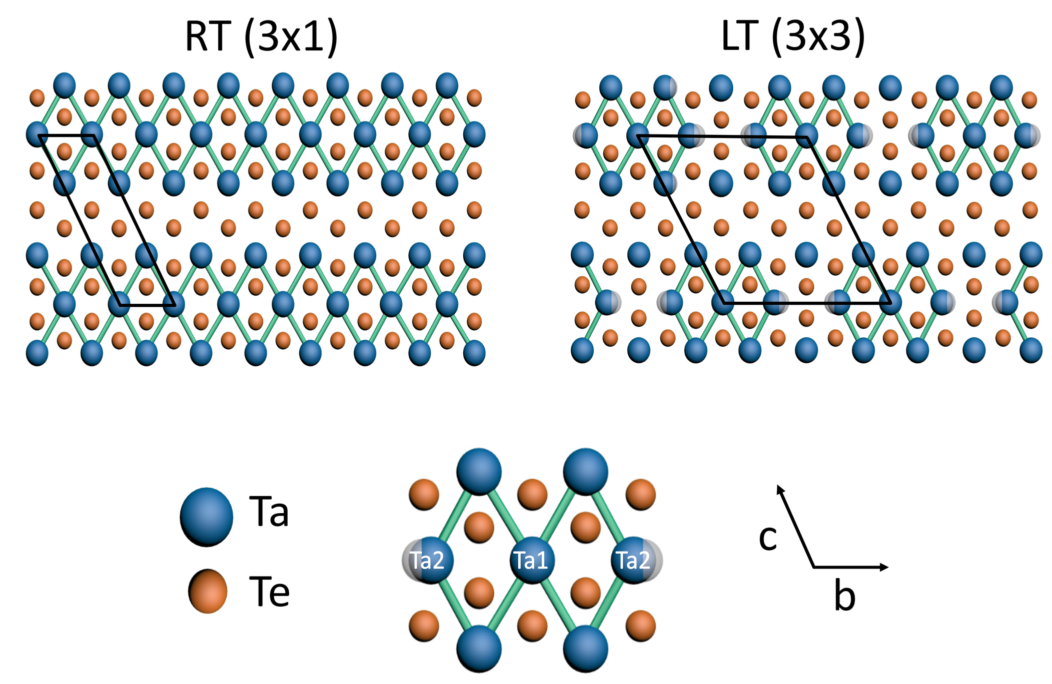


Ultrafast Transmission Electron Microscopy (UTEM) scheme

Electrons E_{kin}	120 keV
$d_{e\text{-beam}}$	100 nm
$FWHM_{Laser}$	25 µm
λ_{Laser}	800 nm
τ_{Laser}	50 fs

Gold in the sample design provides a
1) High thermal conductivity
2) High reflectivity

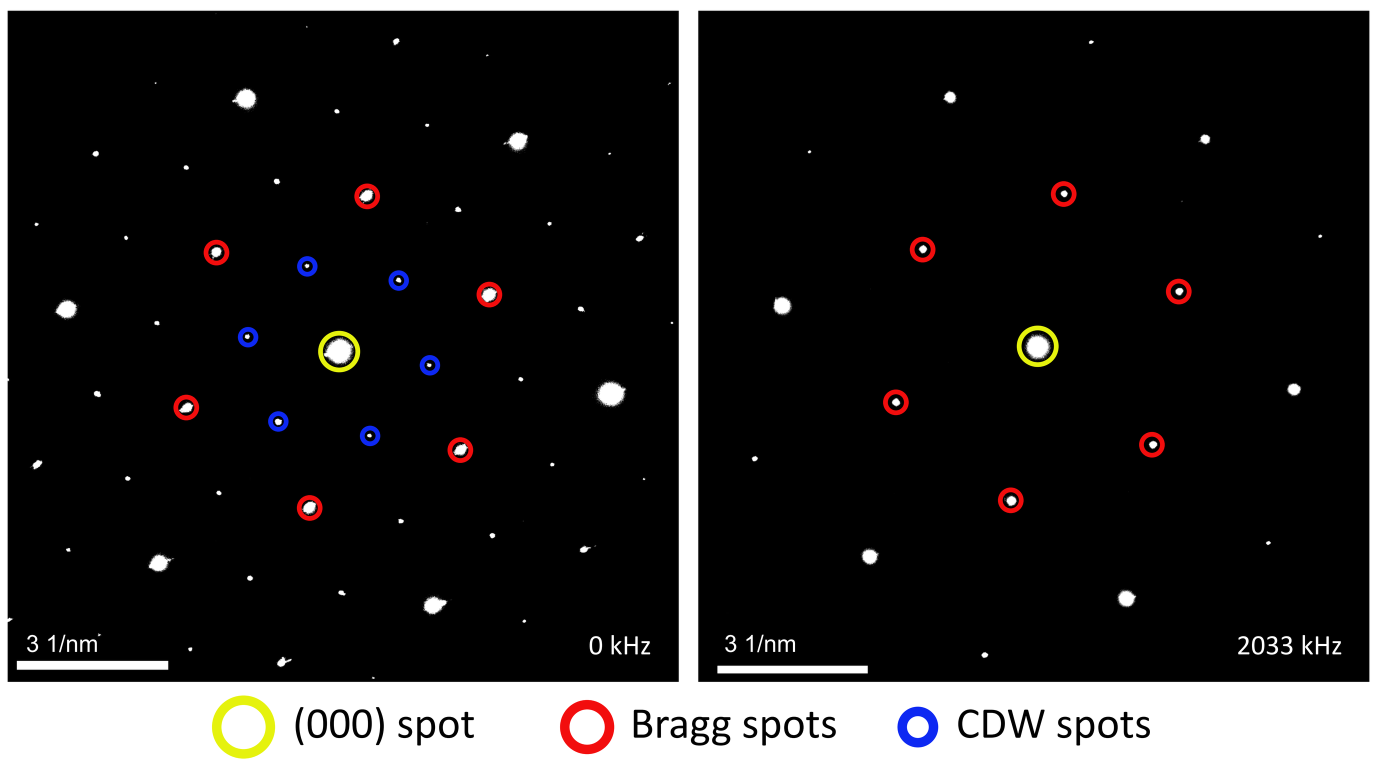
Material system: 1T'-TaTe$_2$



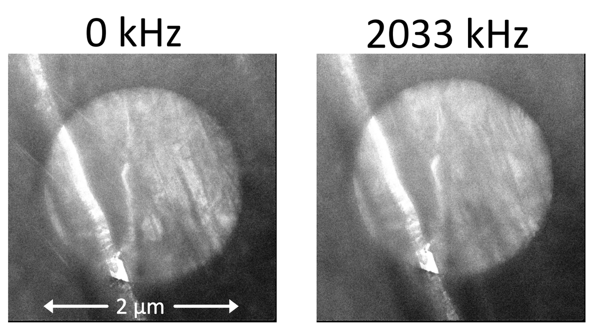
- The **t**ransition **m**etal **d**ichal**c**ogenide (TMDC) 1T'-TaTe$_2$ is a strongly correlated material, which crystallises at room temperature (RT) in a **3x1** superstructure [5].
- In the low temperature (LT) regime below 174 K, 1T'-TaTe$_2$ transforms into a **3x3** superstructure by forming a **C**harge **D**ensity **W**ave (CDW) [5].

Thermal characterization of different sample designs

Sample 3 electron diffraction images

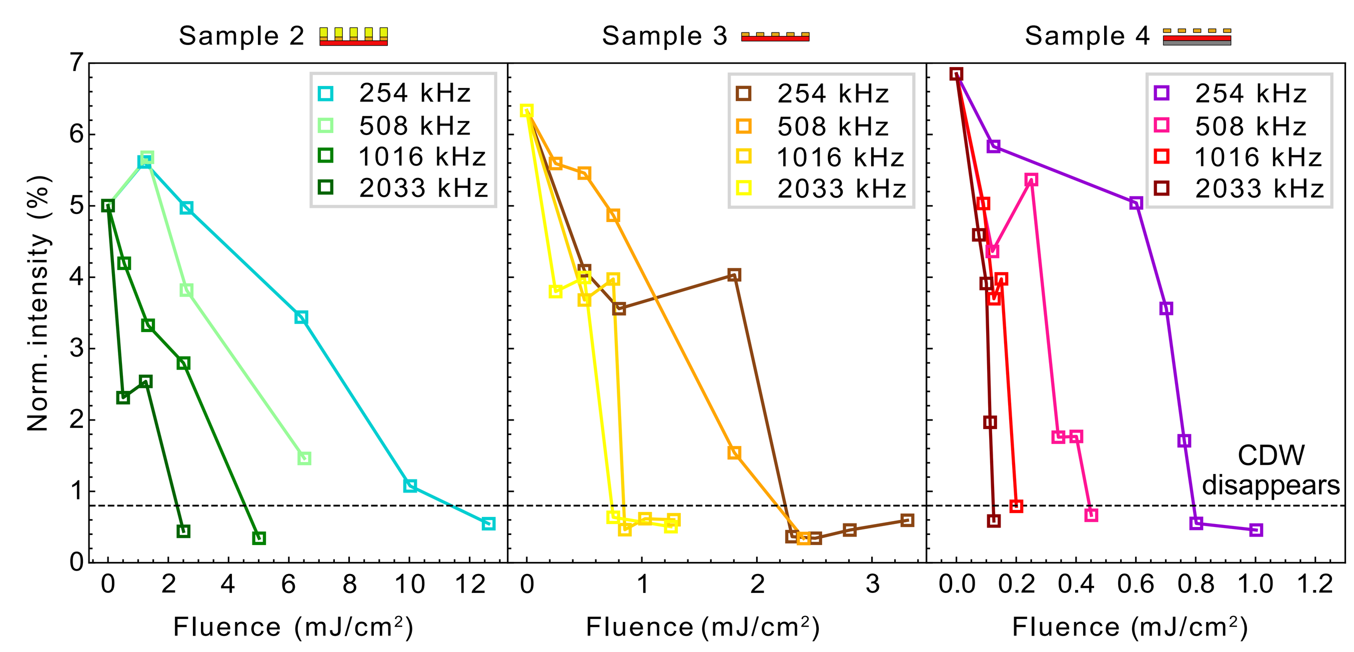


Sample 3 Real space TEM images

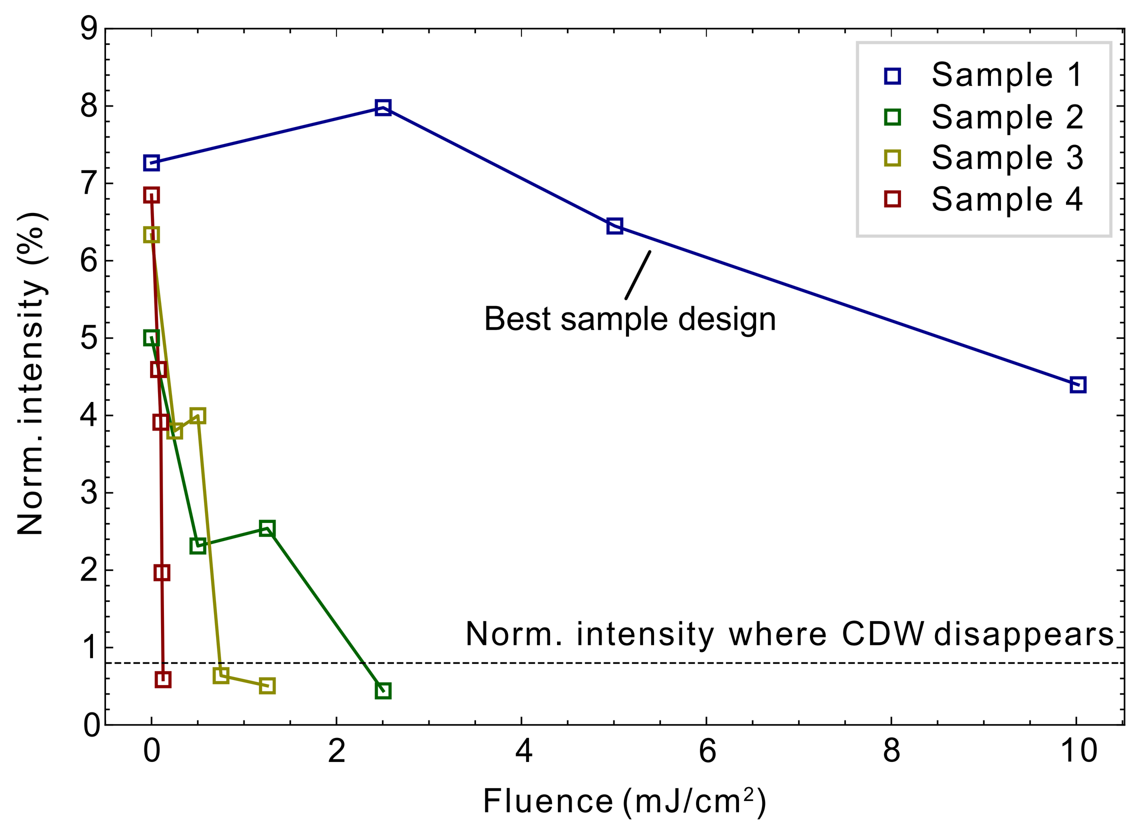


- Contineous electron beam & pulsed pump laser.
- CDW spot intensity is directly related to sample temperature in the probed region.

Fluence dependent heating of the samples 2 to 4 for different pump laser repetition rates

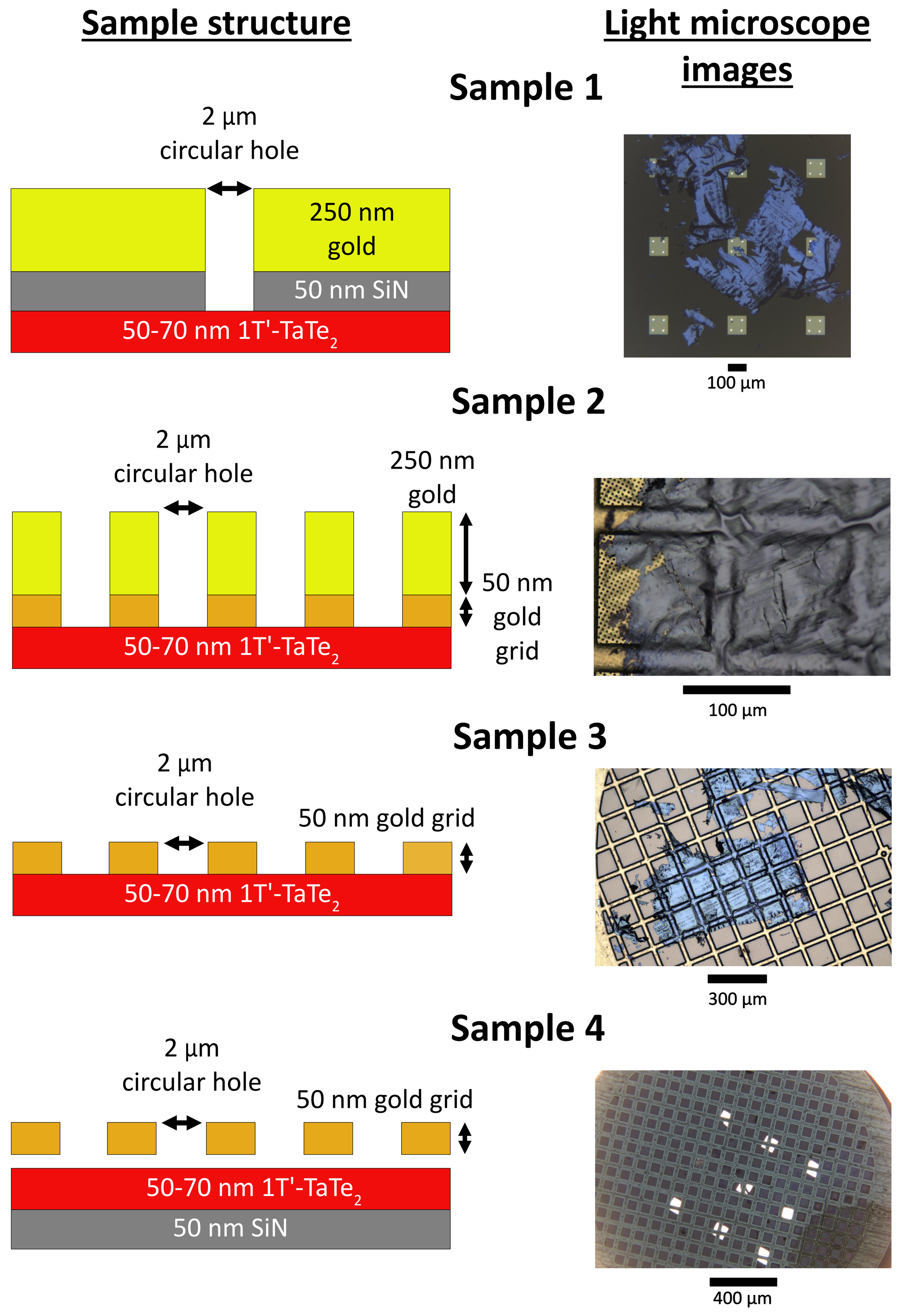


Fluence dependent heating for samples 1 to 4 at 2033 kHz pump laser repetition rate



Repetitive driving at 2 MHz & 10 mJ/cm^2

Sample Designs



Heat dissipation simulation

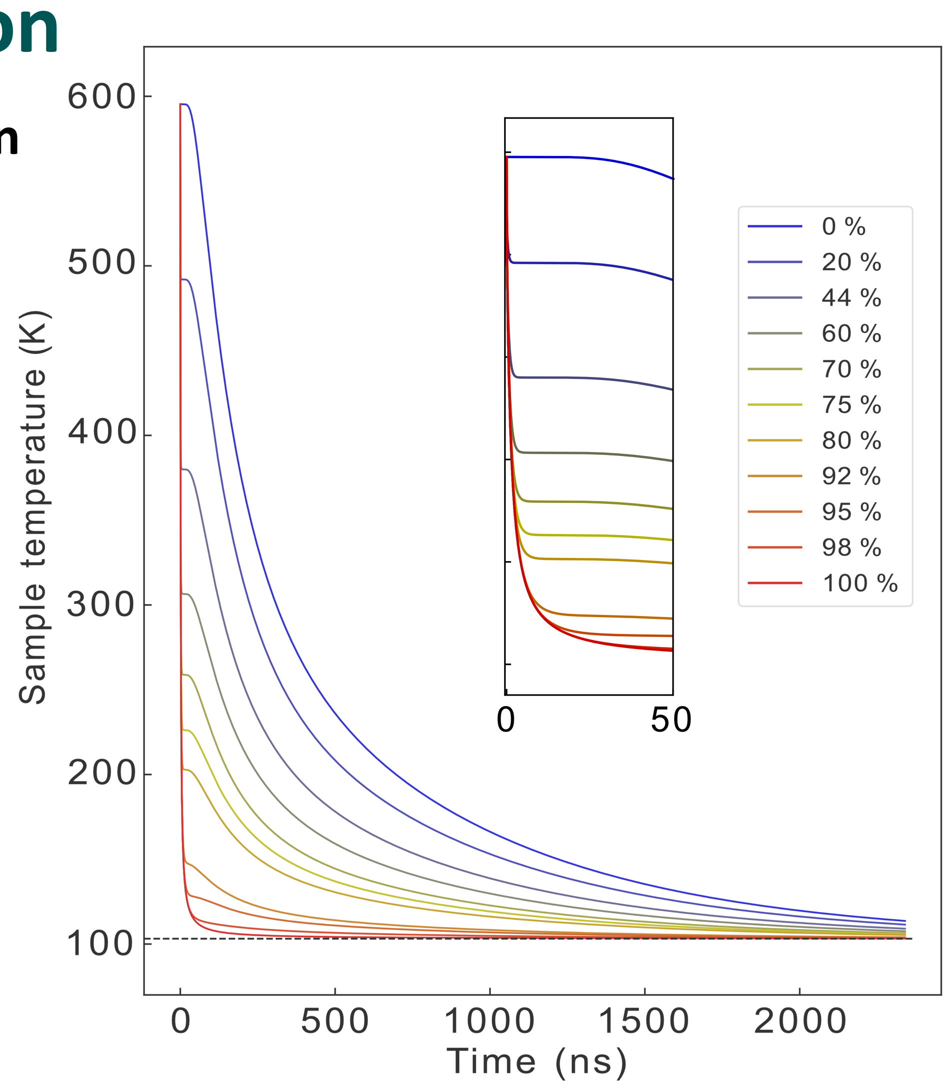
Gold based 2D heat diffusion equation

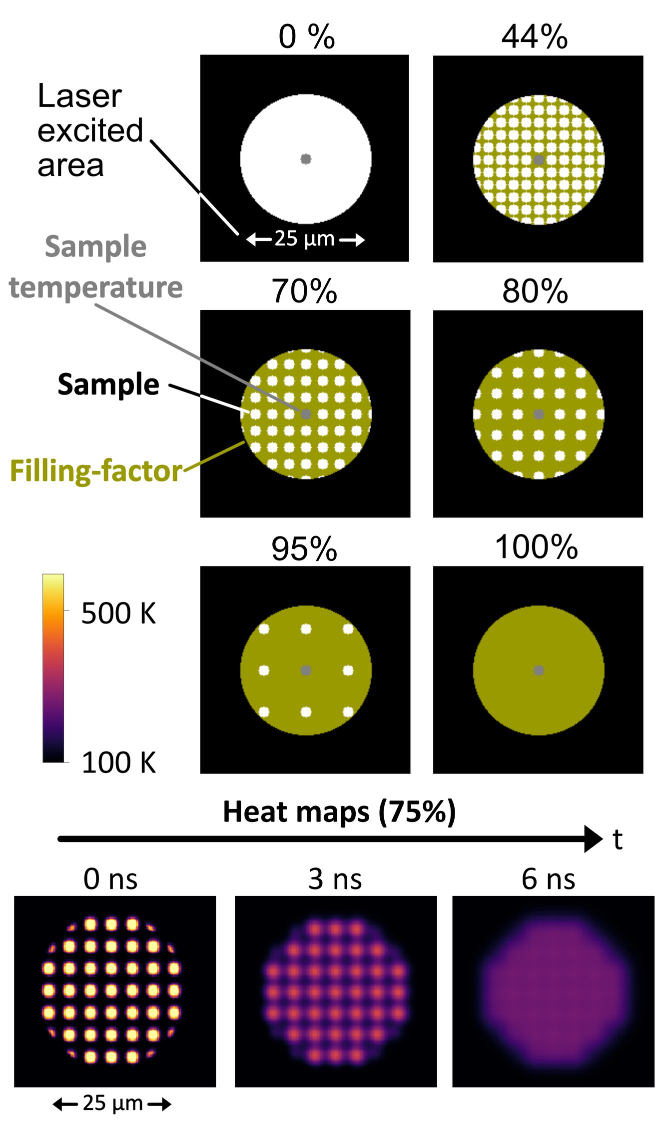
$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \qquad \alpha = \frac{K}{\rho C_p} \text{ [6]}$$

K	Thermal conductivity
ρ	Specific heat capacity
C_p	Mass density

Filling-factor: Percentage in the laser excited area, which does not undergo a temperature increase.

Heat dissipation is strongly coupled to the filling-factor





Summary & Outlook

- **Gold** based sample mask crucially improves heat dissipation and repetition rate (UTEM signal).
- **Decisive factors** in sample designs:
  1) Gold filling-factor
  2) Gold amount on the sample
  3) Degree of gold contact
- Improved sample design holds the potential to contribute to the advancement of UED measurements.

Discover **hidden non-equilibrium** states [3][4]

References

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[5] T. Sörgel et al., Mater. Res. Bulletin 41, 987-1000 (2006)

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Acknowledgements

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