Entwicklung eines Vorderseitenmodells für die Laser-Flash-Analyse

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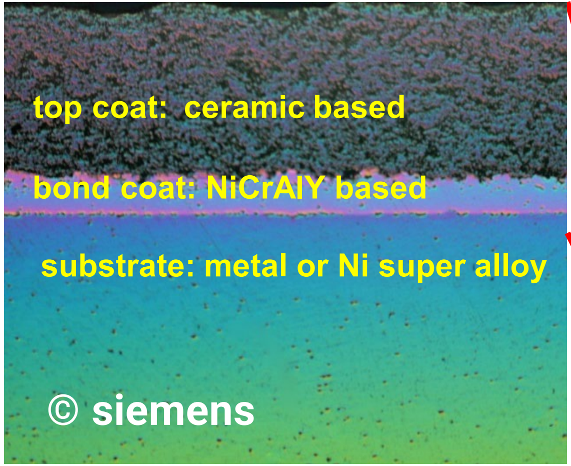
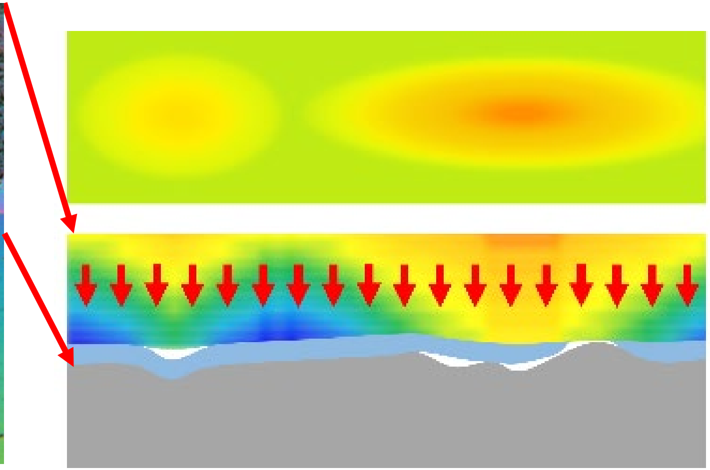
zero carbon

Motivation – LFA multilayer systems

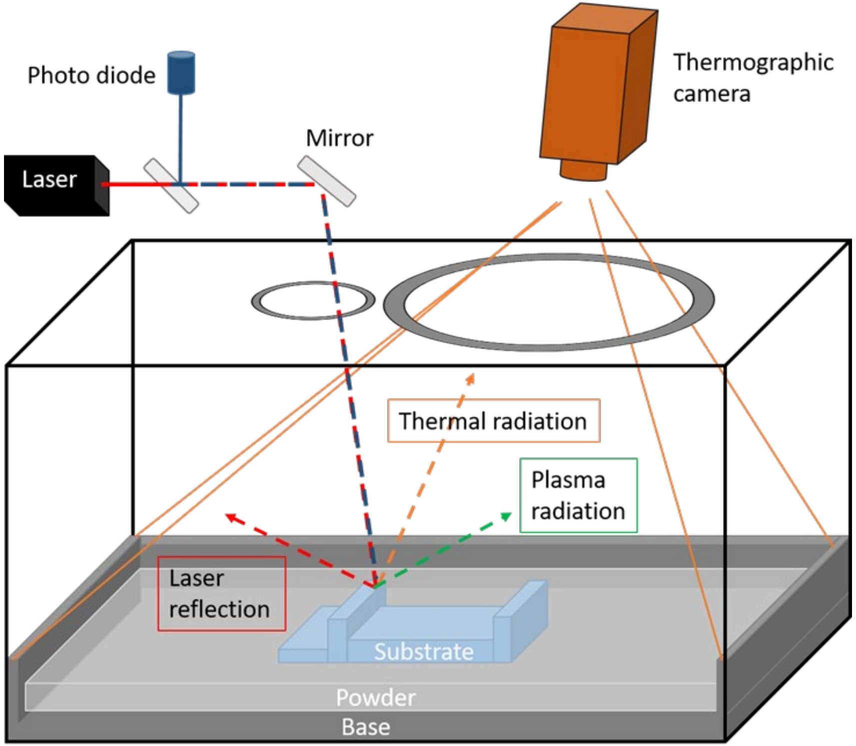


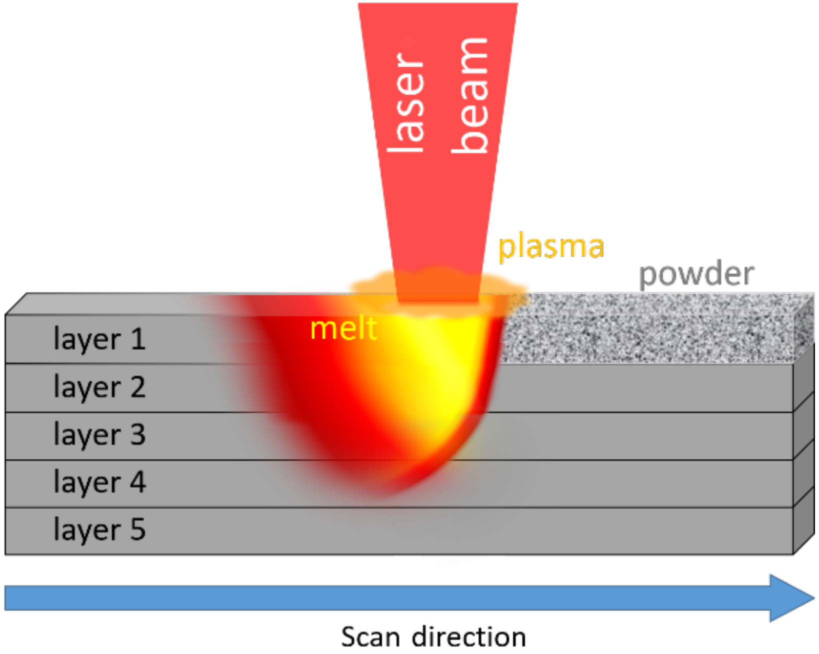


$$R_{th} \sim \frac{1}{\lambda}$$

$$\lambda(T) = \alpha(T) \cdot c_p(T) \cdot \rho(T)$$

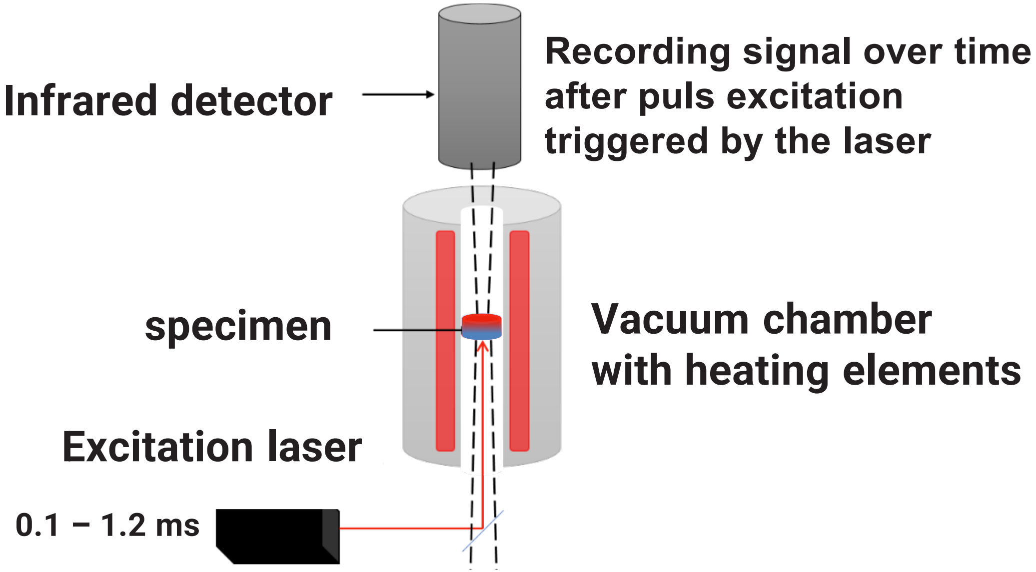
Motivation – Additive Manufacturing



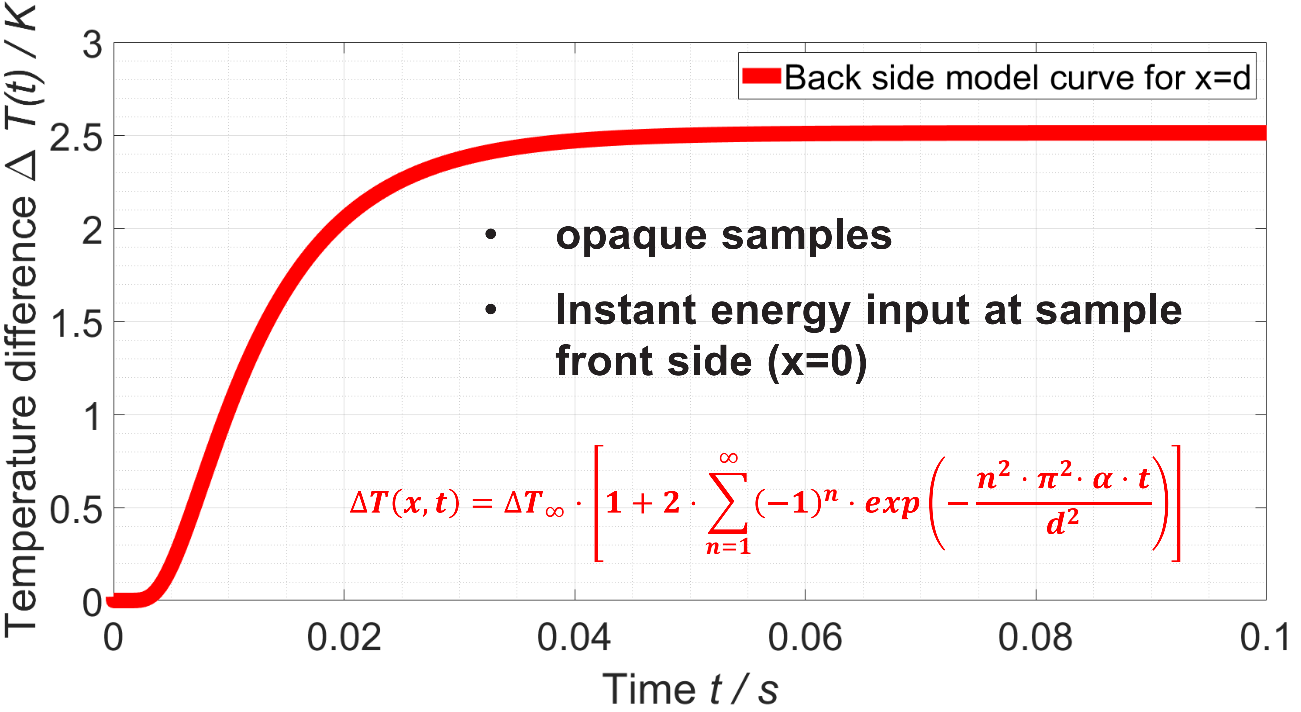


LFA Setup

RT – 3000 K

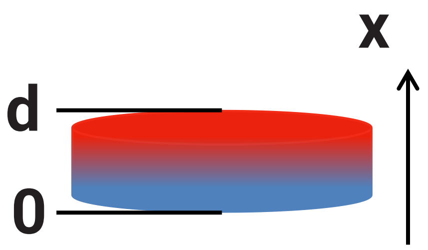


Adiabatic model

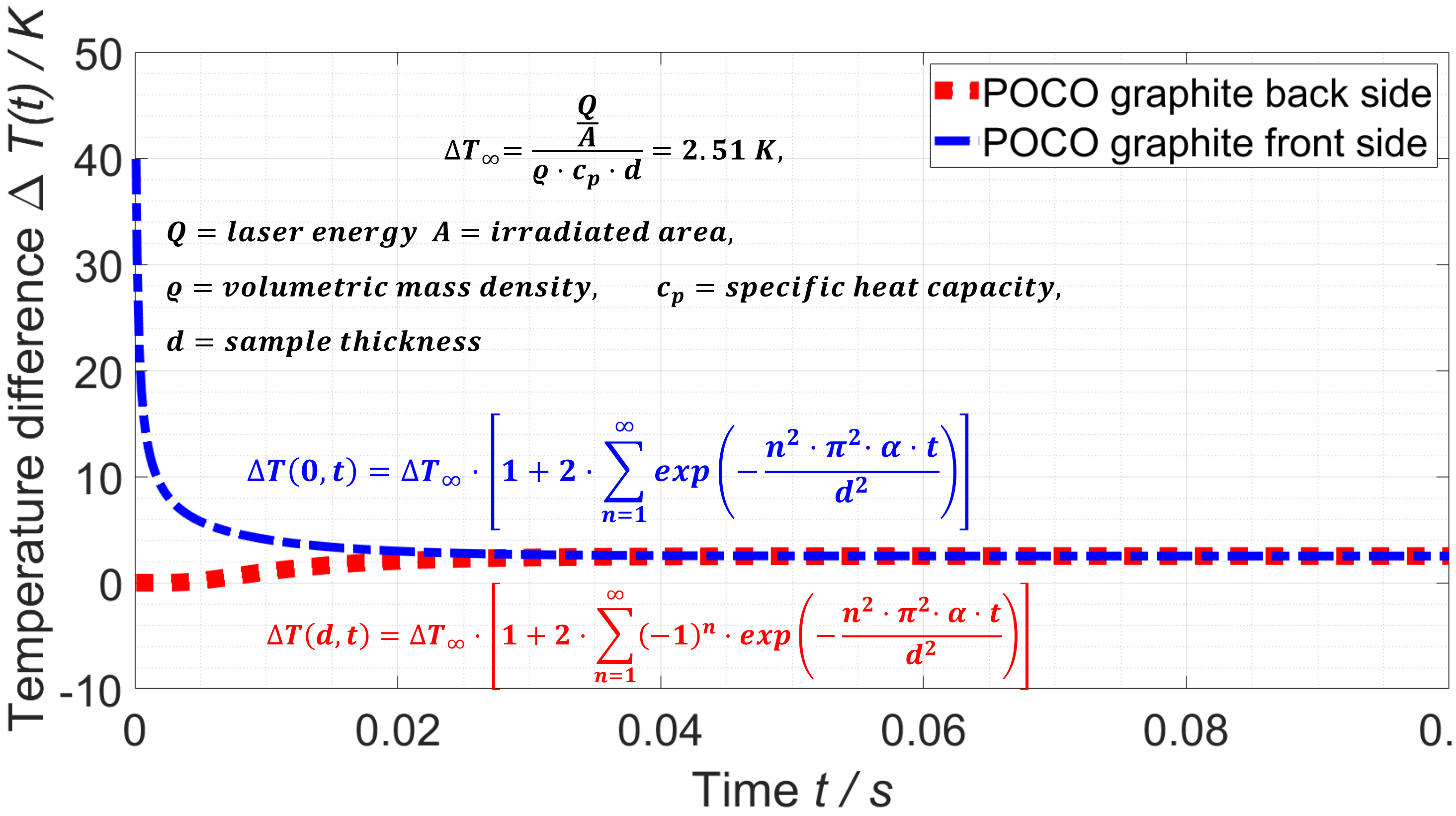


- **opaque samples**
- **Instant energy input at sample front side (x=0)**

$$\Delta T(x,t) = \Delta T_{\infty} \cdot \left[1 + 2 \cdot \sum_{n=1}^{\infty} (-1)^n \cdot exp\left(-\frac{n^2 \cdot \pi^2 \cdot \alpha \cdot t}{d^2} \right) \right]$$



Temperature development adiabatic model



$\varrho = 1780 \frac{\mathrm{kg}}{\mathrm{m}^3}$

$c_p = 709 \frac{\mathrm{J}}{\mathrm{kg \cdot K}}$

$\alpha = 75 \cdot 10^{-6} \frac{m^2}{s}$

$d = 2.49 \cdot 10^{-3}\ \mathrm{m}$

$Q = 1\ J$

$\Delta T_\infty = 2.51\ K$

Convolution methods

- Numerical convolution in the Fourier domain is achieved by pointwise multiplication of the discrete function values of the pulse and the temperature evolution in the frequency domain

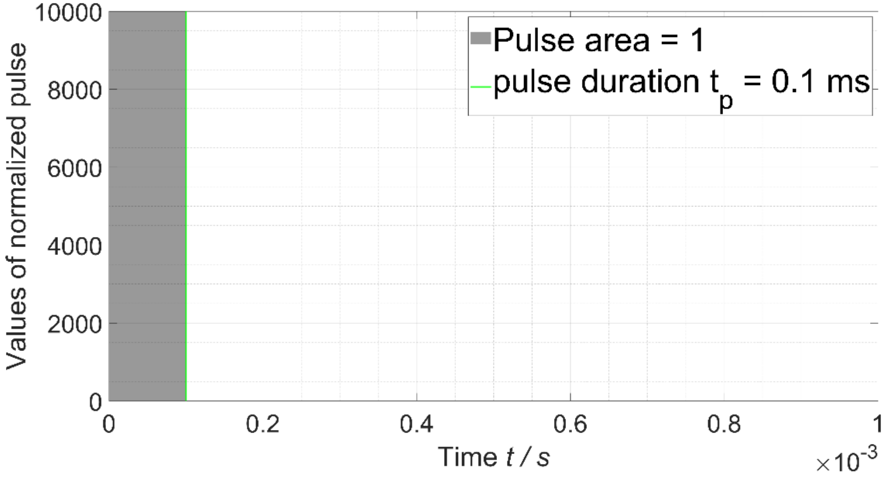
- Analytical convolution in the time domain involves solving the convolution integral, using mathematically continuous definitions for the pulse and temperature evolution

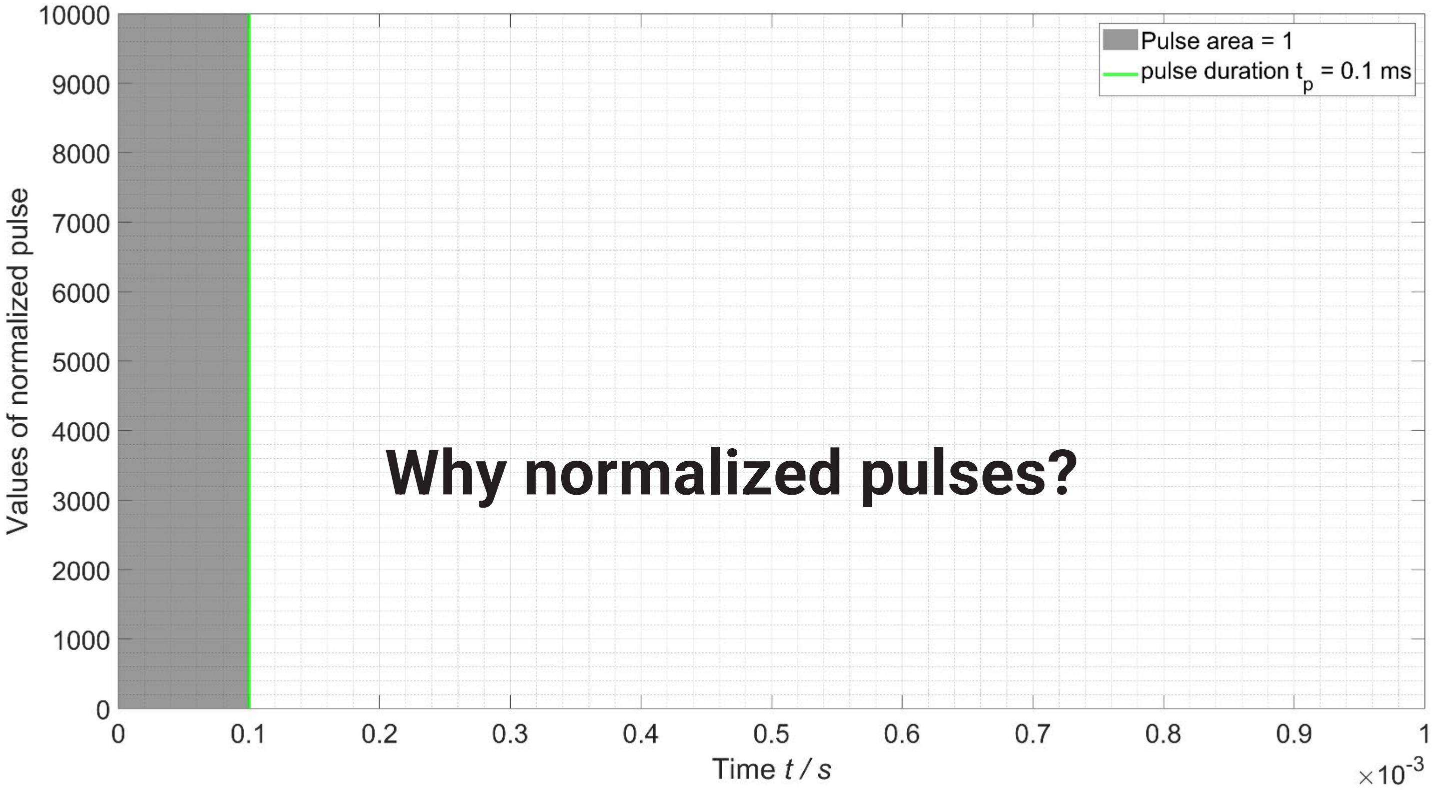
Analytical convolution

$$P_{\sqcap}(t) = \begin{cases} P_{\sqcap} & for\ 0 < t \leq t_p \\ 0 & for\ t > t_p \end{cases}$$

$$Q = \int_0^{t_p} P(t)\,dt = P_{\sqcap} \cdot t_p \ := \ 1\,J$$

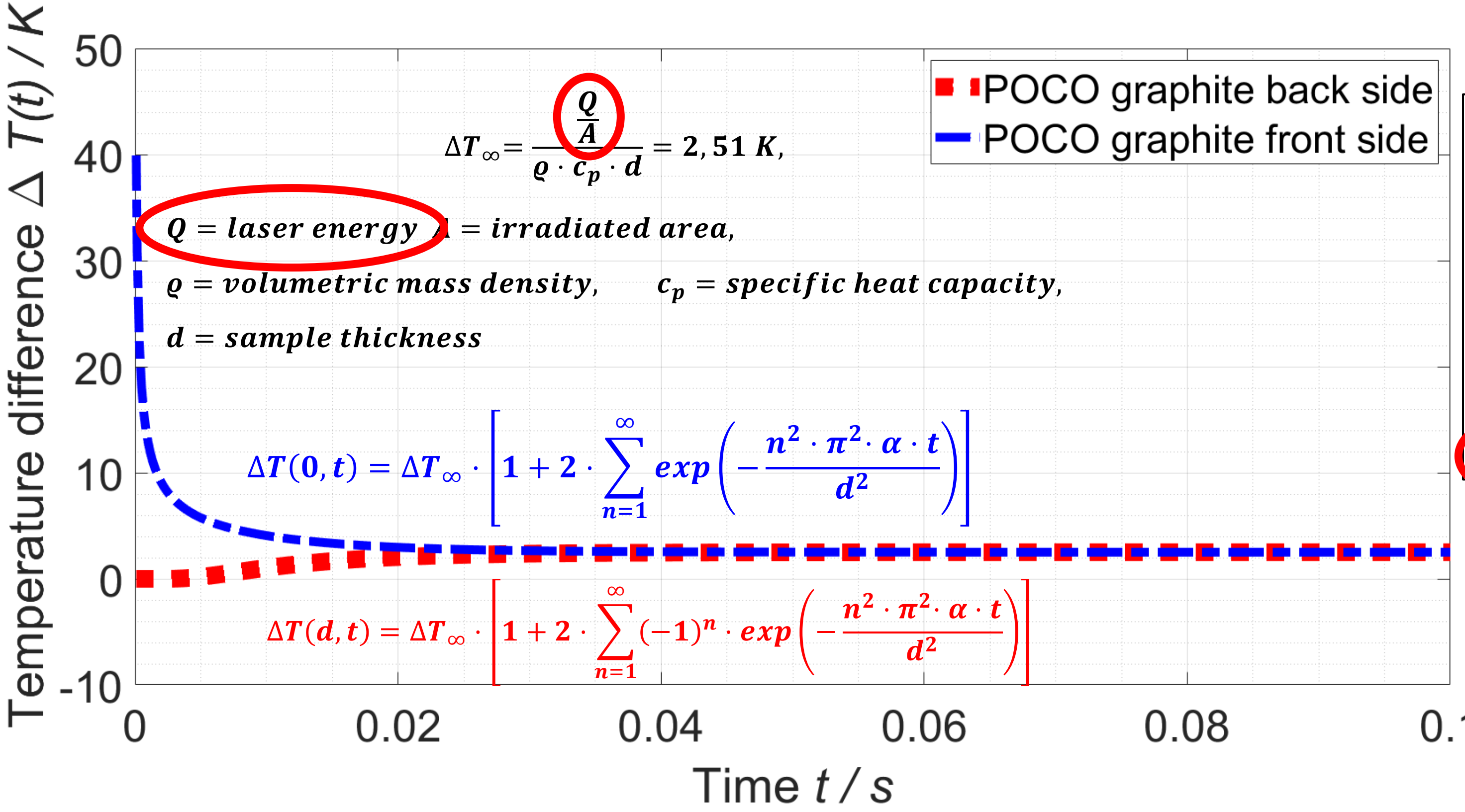
$$\rightarrow P_{\sqcap} = \frac{1}{t_p}\frac{J}{s}$$





Why normalized pulses?

Temperature development adiabatic model



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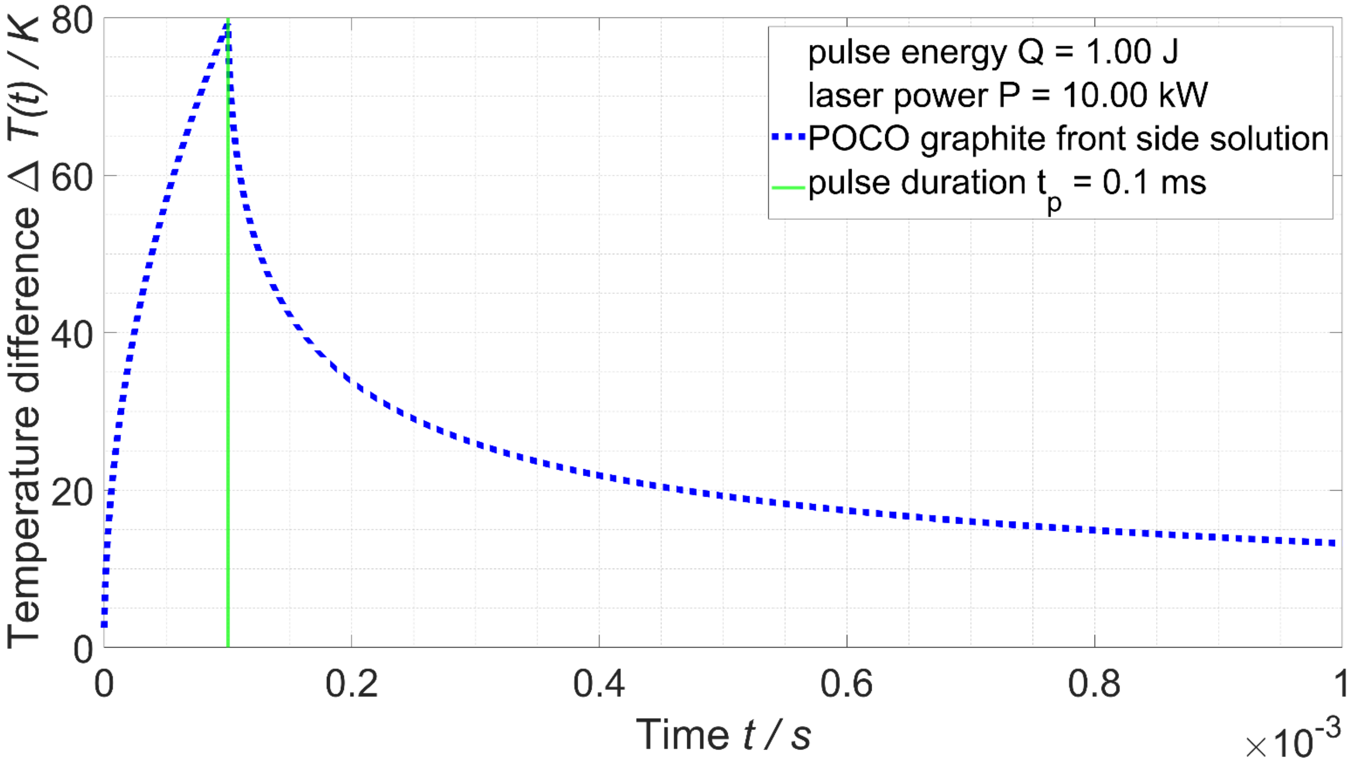
Analytical convolution

$$\Delta T_P = \int_0^{\infty} P(t') \cdot \Delta T(t-t')dt' = \int_0^{t_p} P(t') \cdot \Delta T(t-t')\, dt'$$

$$\Delta T_{f,P_{\sqcap}} = \Delta T_{\infty} \cdot \left[1 + \frac{2}{t_p} \cdot \sum_{n=1}^{\infty} \frac{l^2}{\alpha n^2 \pi^2} \cdot exp\left(-\frac{\alpha n^2 \pi^2 t}{d^2}\right) \cdot \left(exp\left(\frac{\alpha n^2 \pi^2 t_p}{d^2}\right) - 1 \right) \right]$$

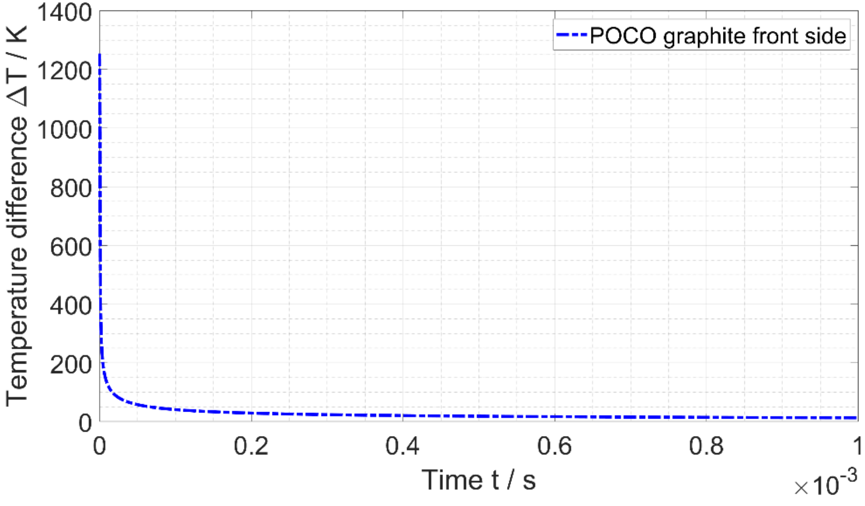
Analytical convolution

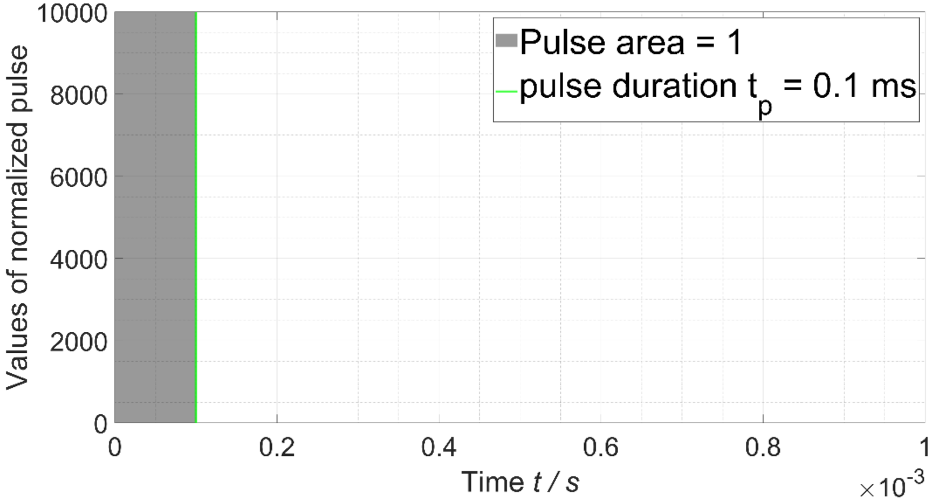


$\Delta T_{\infty} = 2.51\ K$

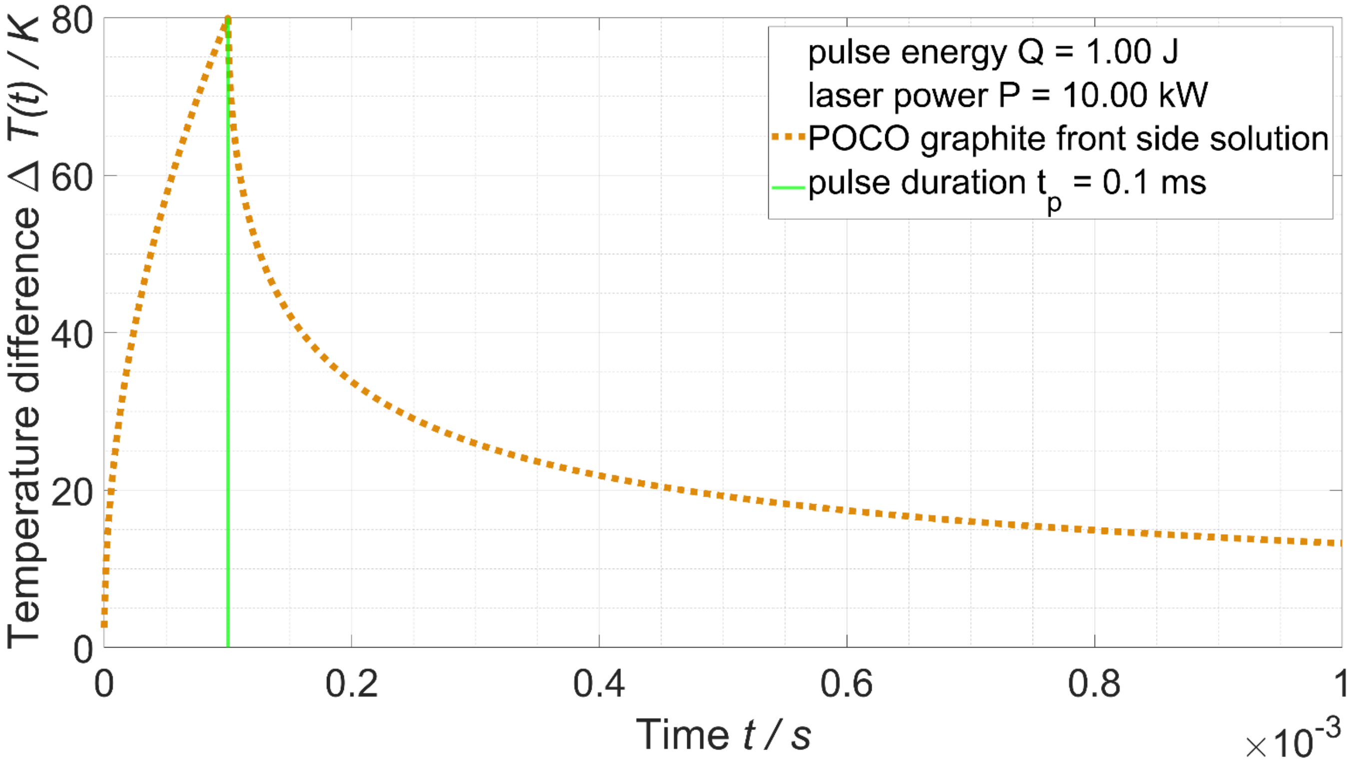
Numerical convolution

1. DFT of temperature curve and pulse
2. Pointwise multiplication of both curves
3. Applying DFT to the product



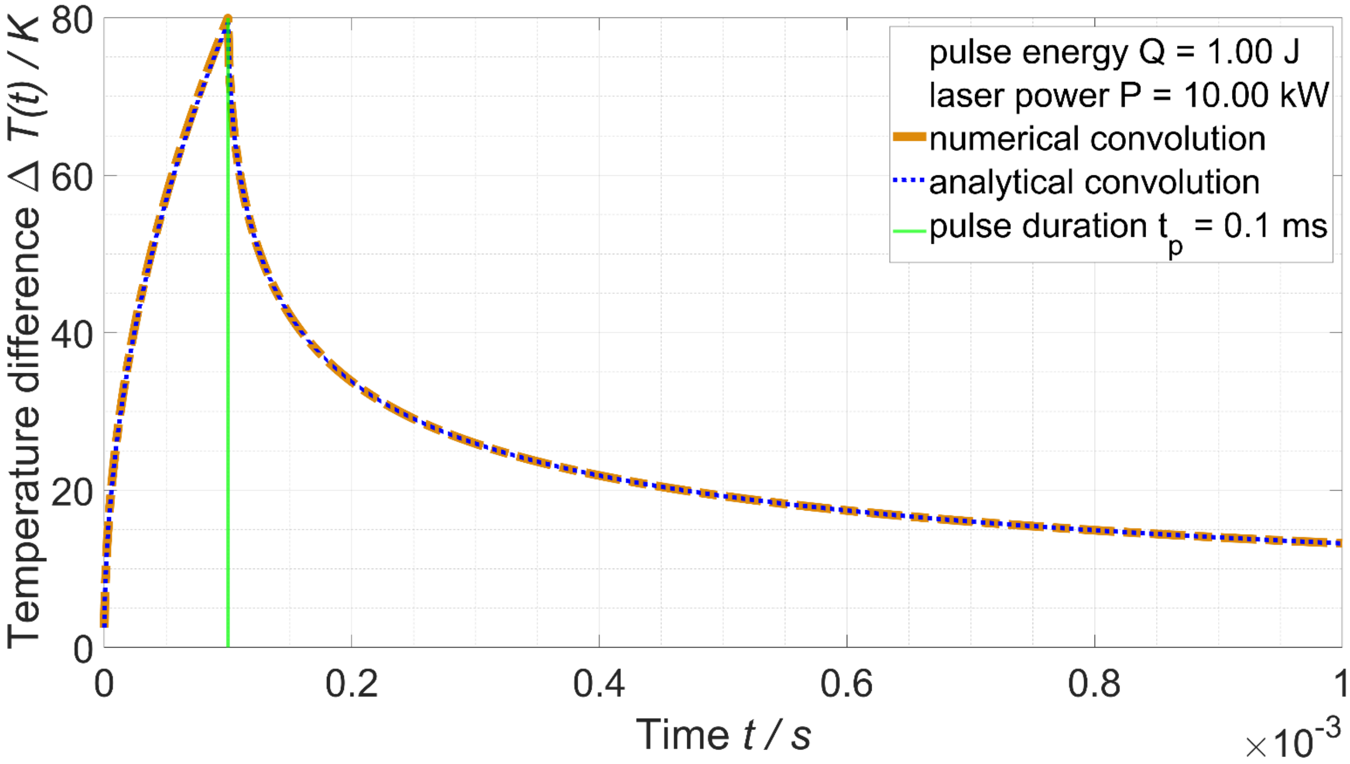


Numerical convolution



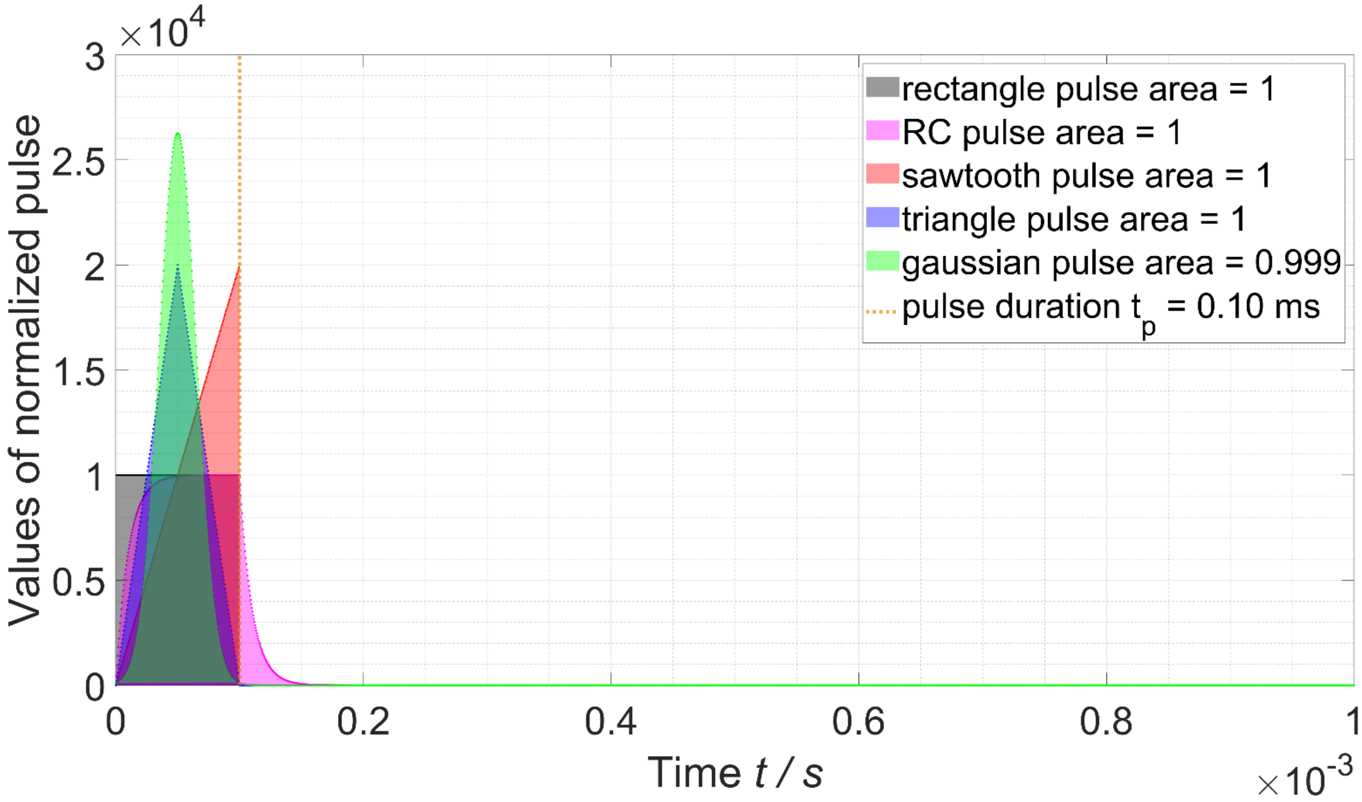
$\Delta T_\infty = 2.51\ K$

Comparison

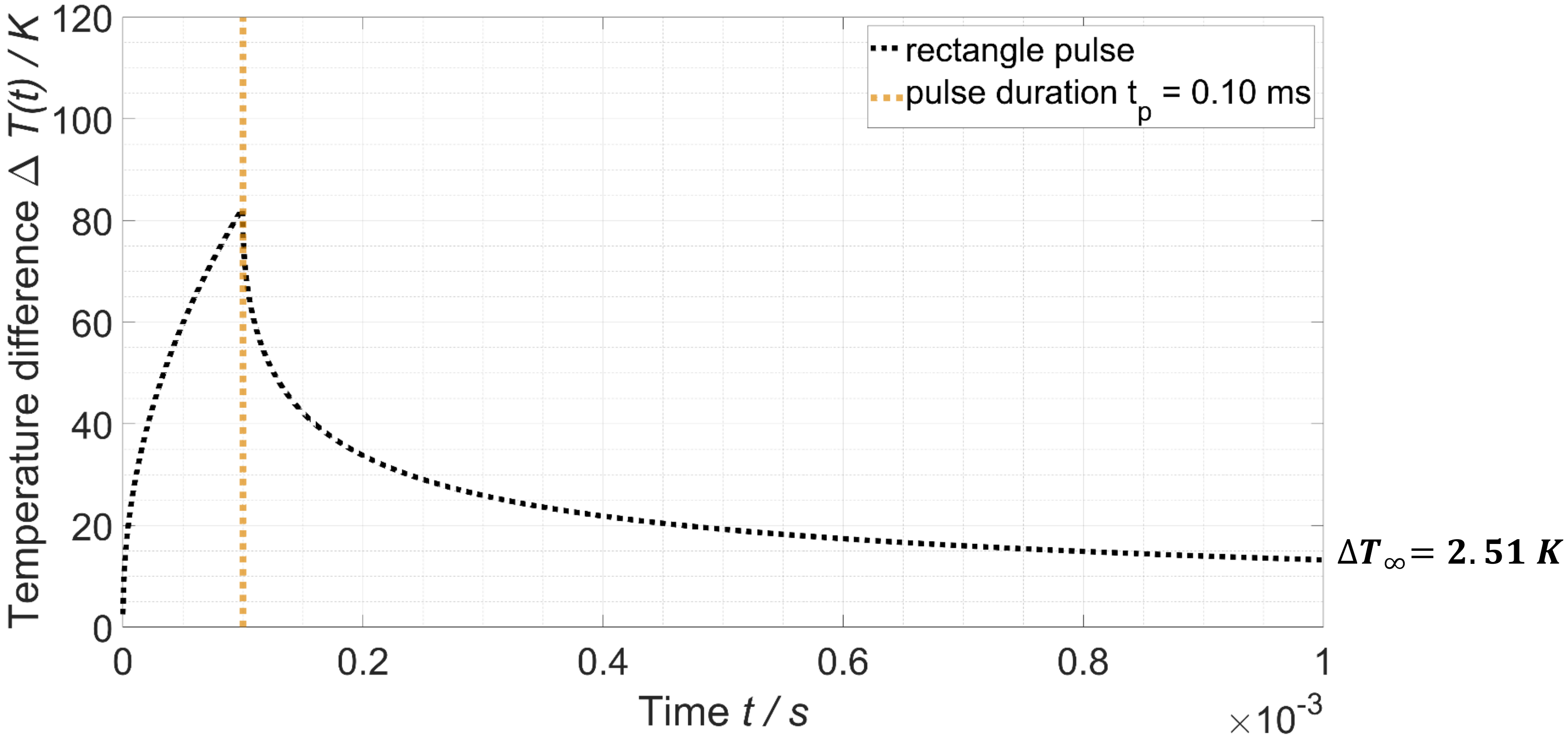


$\Delta T_{\infty} = 2.51\ K$

Pulse shape variation



Comparison of pulse shape effect



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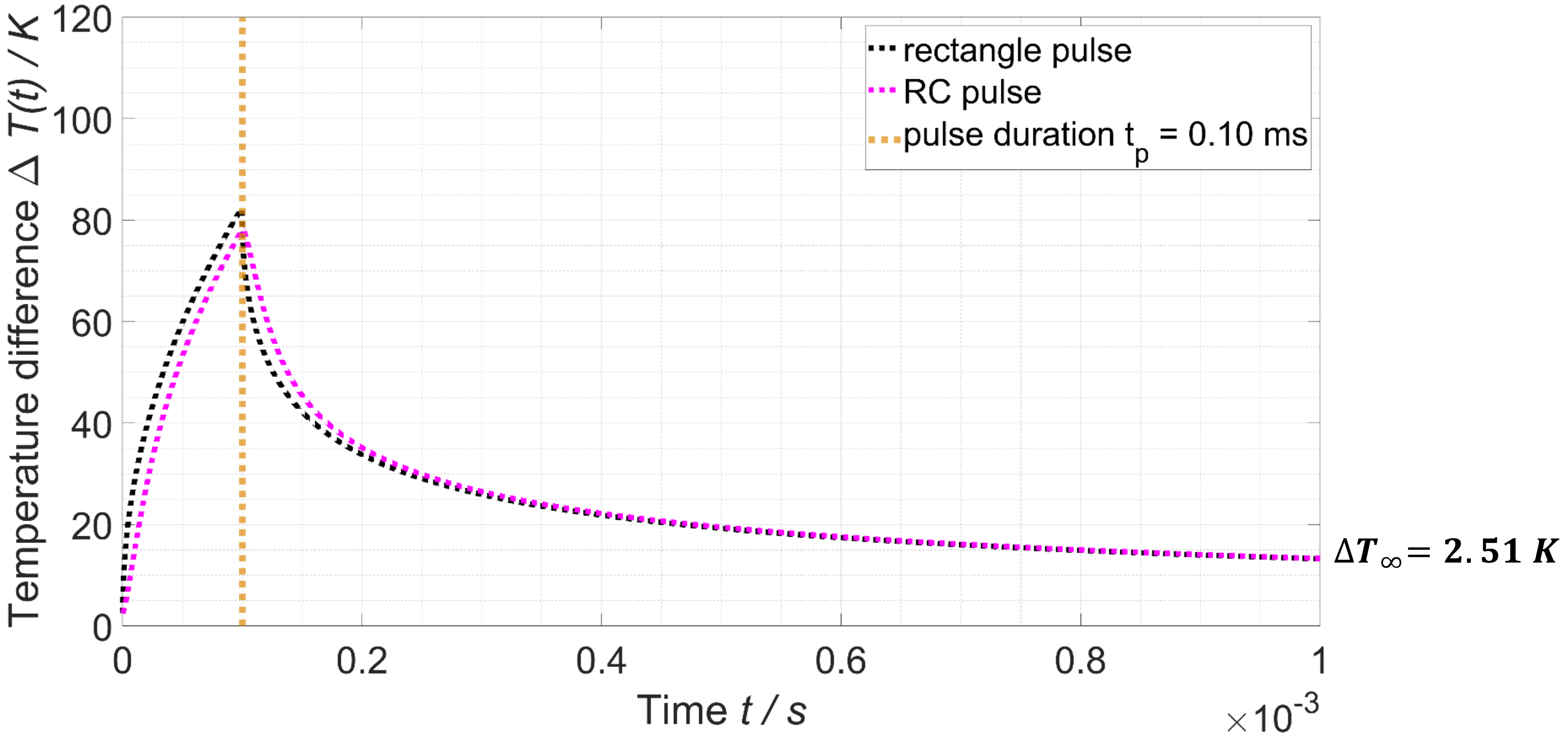

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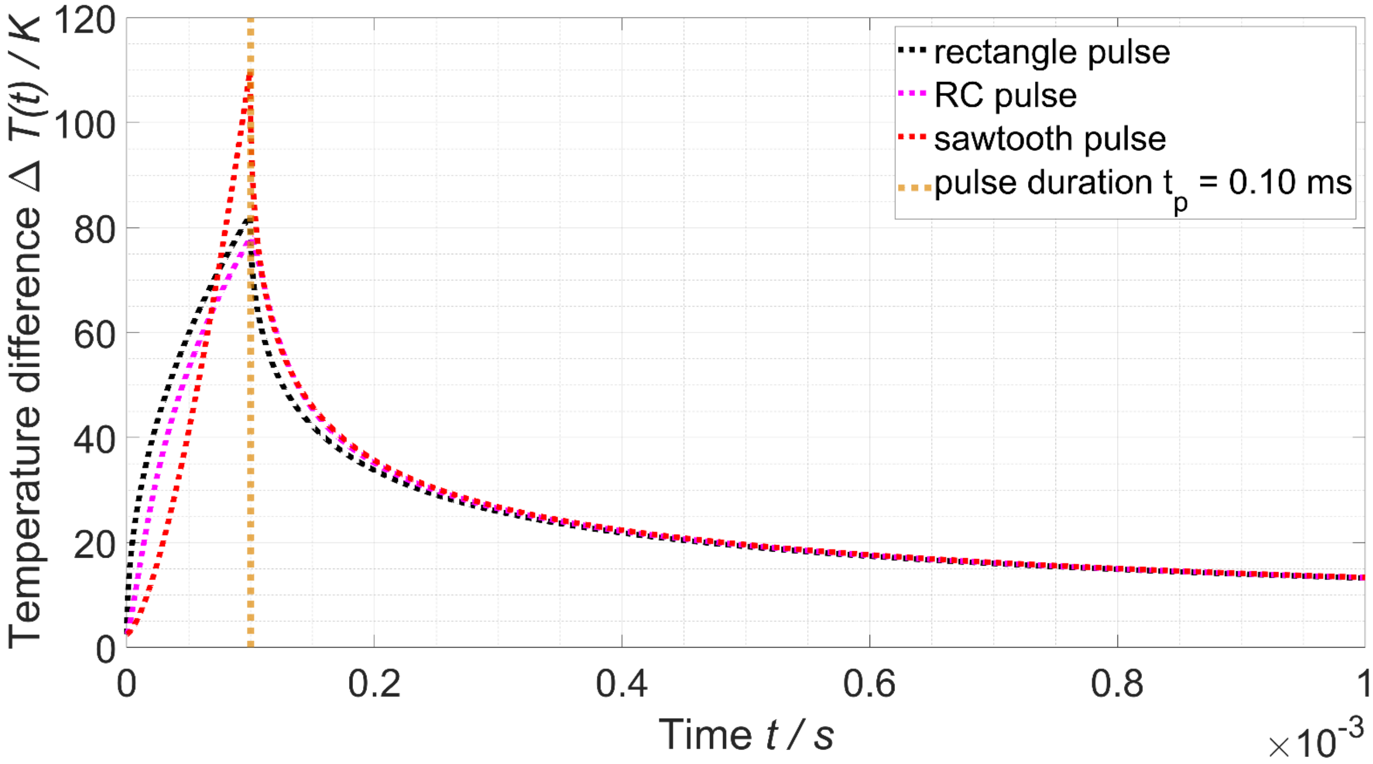

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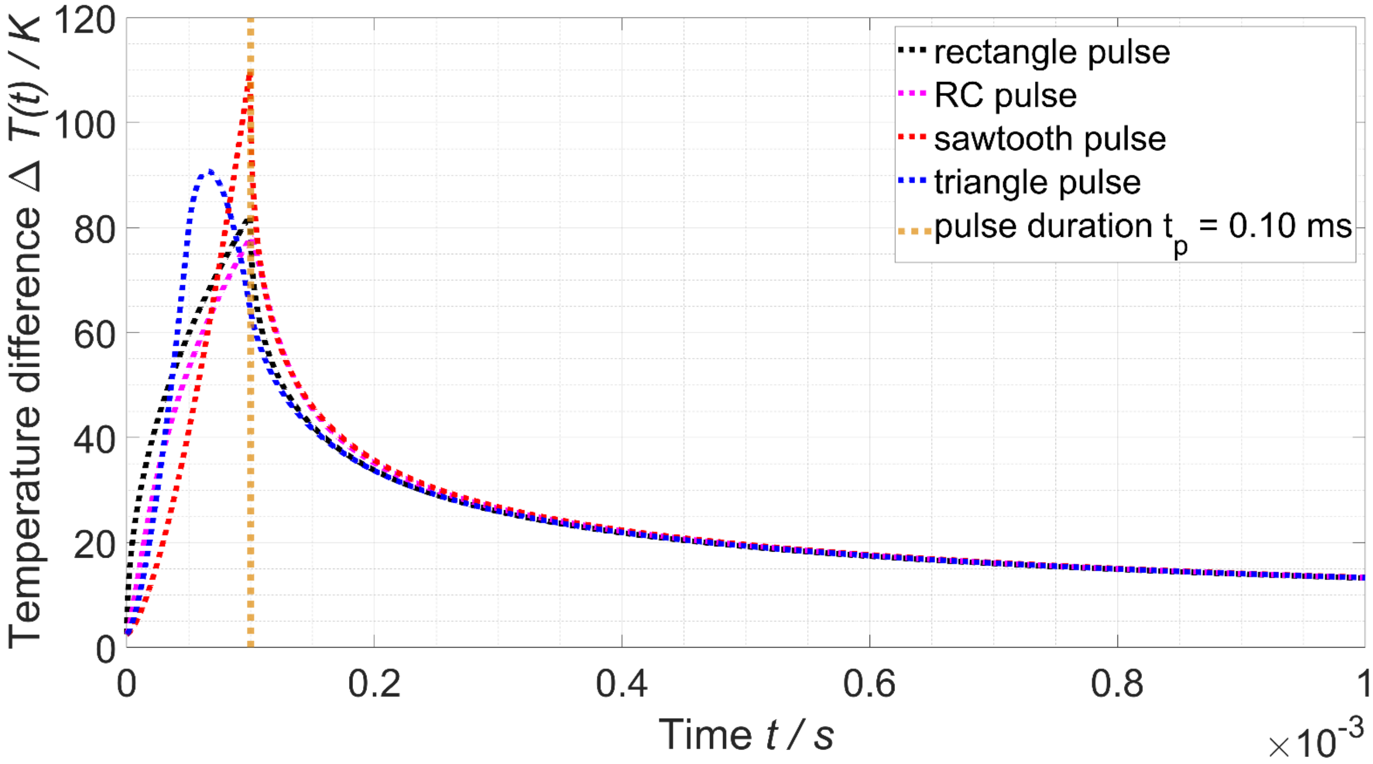

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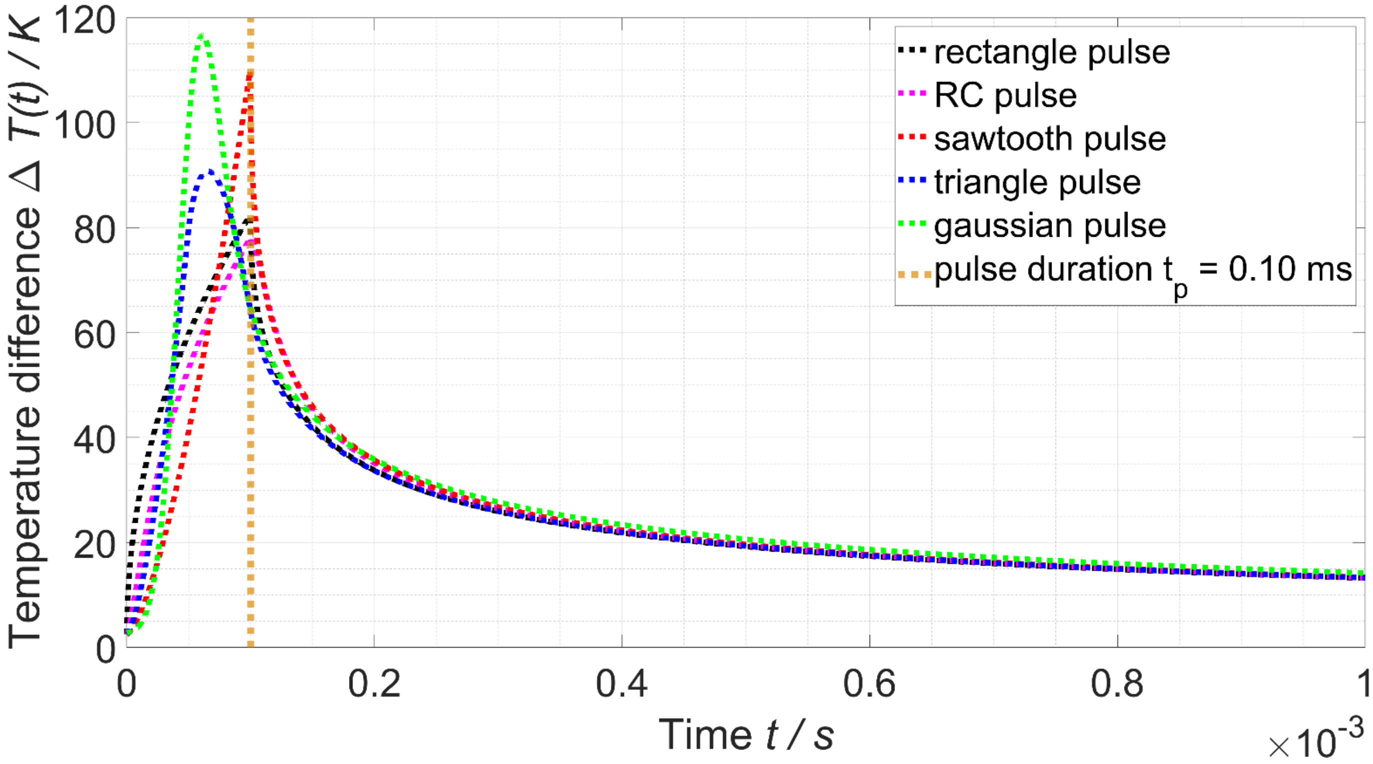

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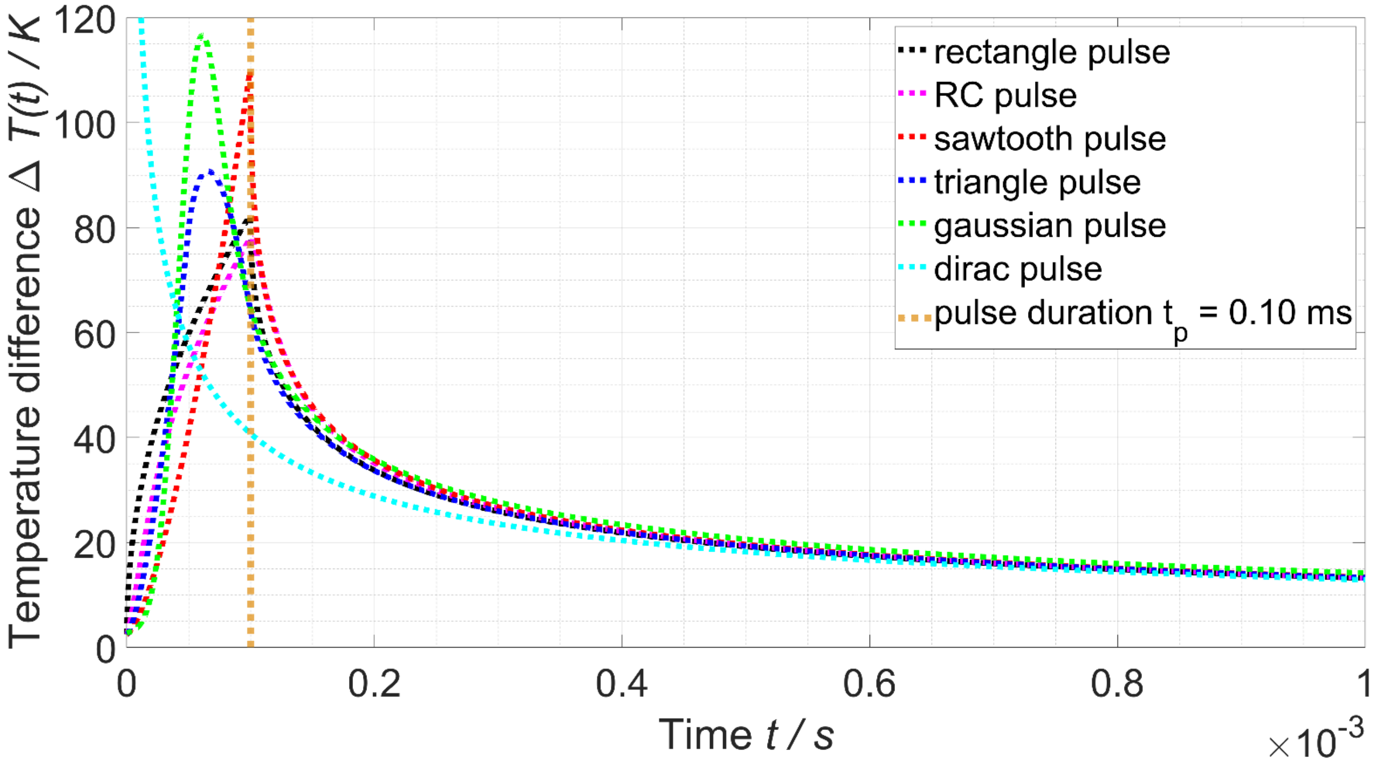

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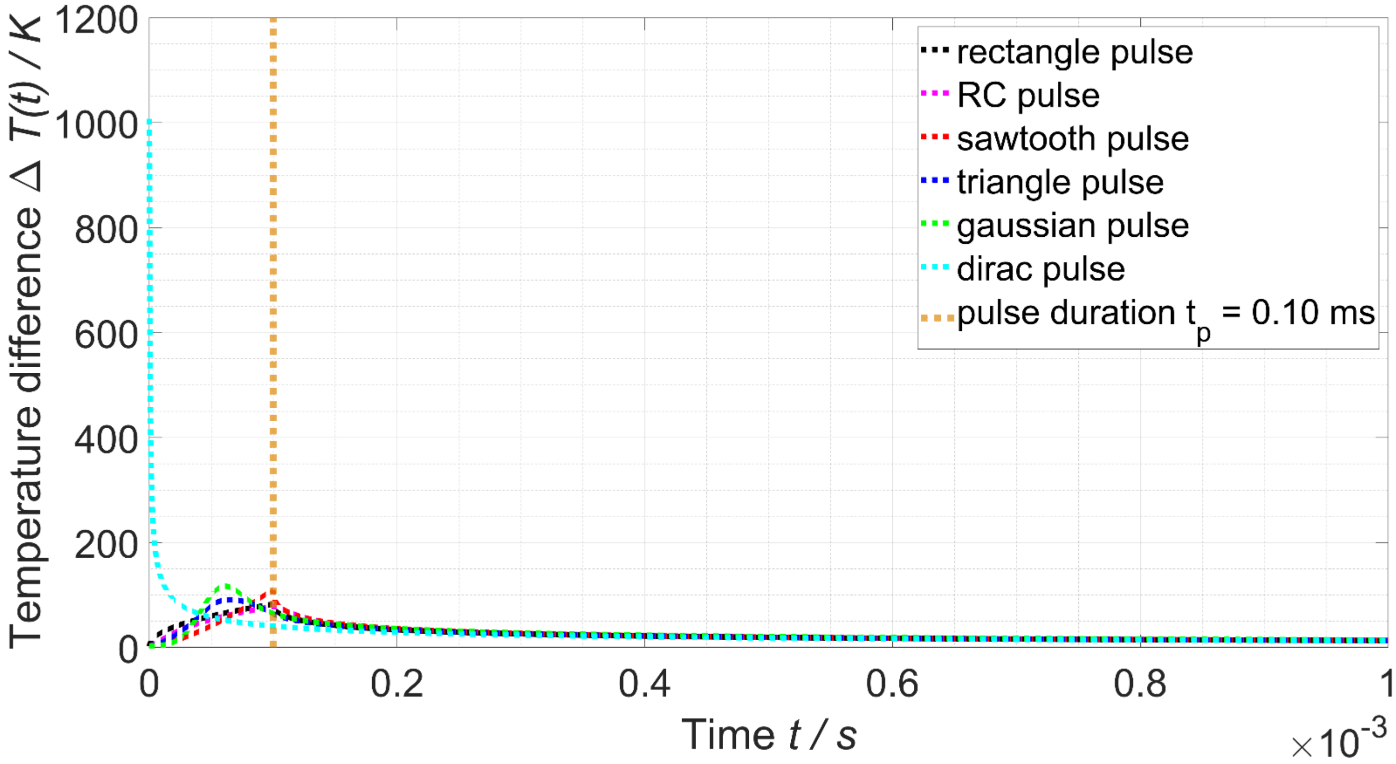
Comparison of pulse shape effect



$\Delta T_{\infty} = 2.51\ K$

Conclusion

- Both convolution methods show similar temperature over time curves
- DFT convolutions for other pulse shapes show plausible temperature profiles
- A more realistic consideration of the front-side temperature evolution is possible through convolution with finite pulses
  - Finite temperature rise near $t = 0$

- TO-DO:
  - Investigate temperature dependence of thermal diffusivity in the models
  - Use models which consider thermal losses
  - Collect measurement data to test the applicability of the models

Thank you
for your attention!

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