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# Analysis of Transient Heating of Phosphor Coatings

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Standards  
Certification  
Education & Training  
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- Develops with his close associates thermometry based on phosphor materials. Applications include turbine engines, heat pump efficiency studies, motor-surface measurements, aerodynamic model thermometry, and other applications. He has coauthored about 100 papers and has 9 patents. His current plans concern the development of phosphor thermometry, new optical materials (including nanophosphors and LEDs), and fiber sensor applications.



# Outline

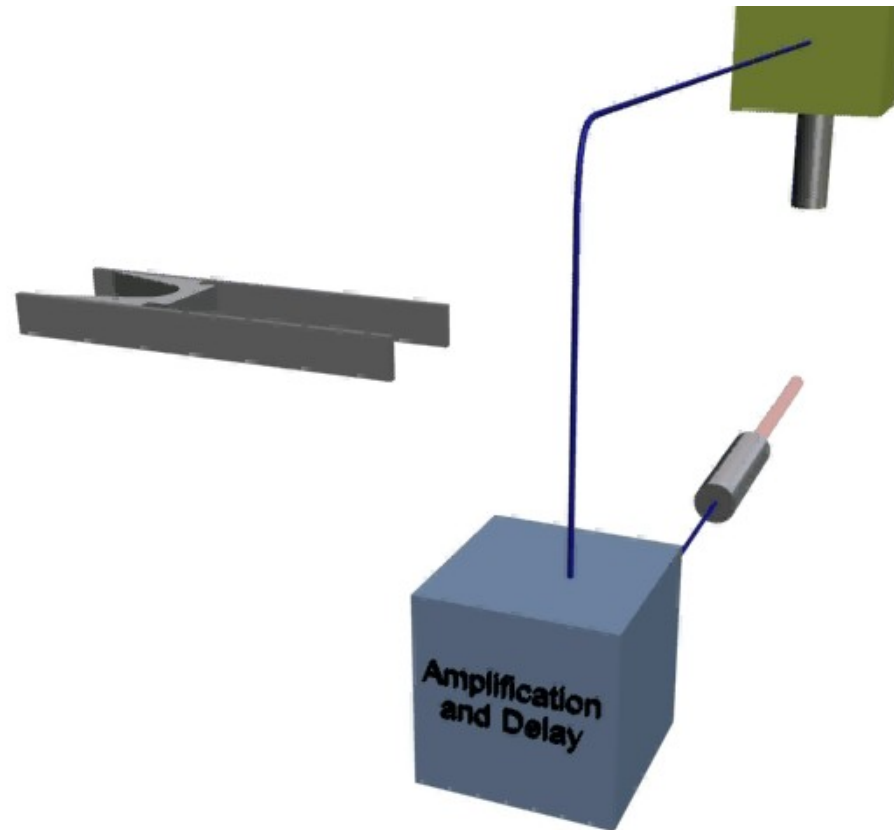


- Justification
- Areas of Application
- Railgun Example of Transient Heating
- Modeling and its Results
- Some previous test results evaluated in light of the model
- Conclusion

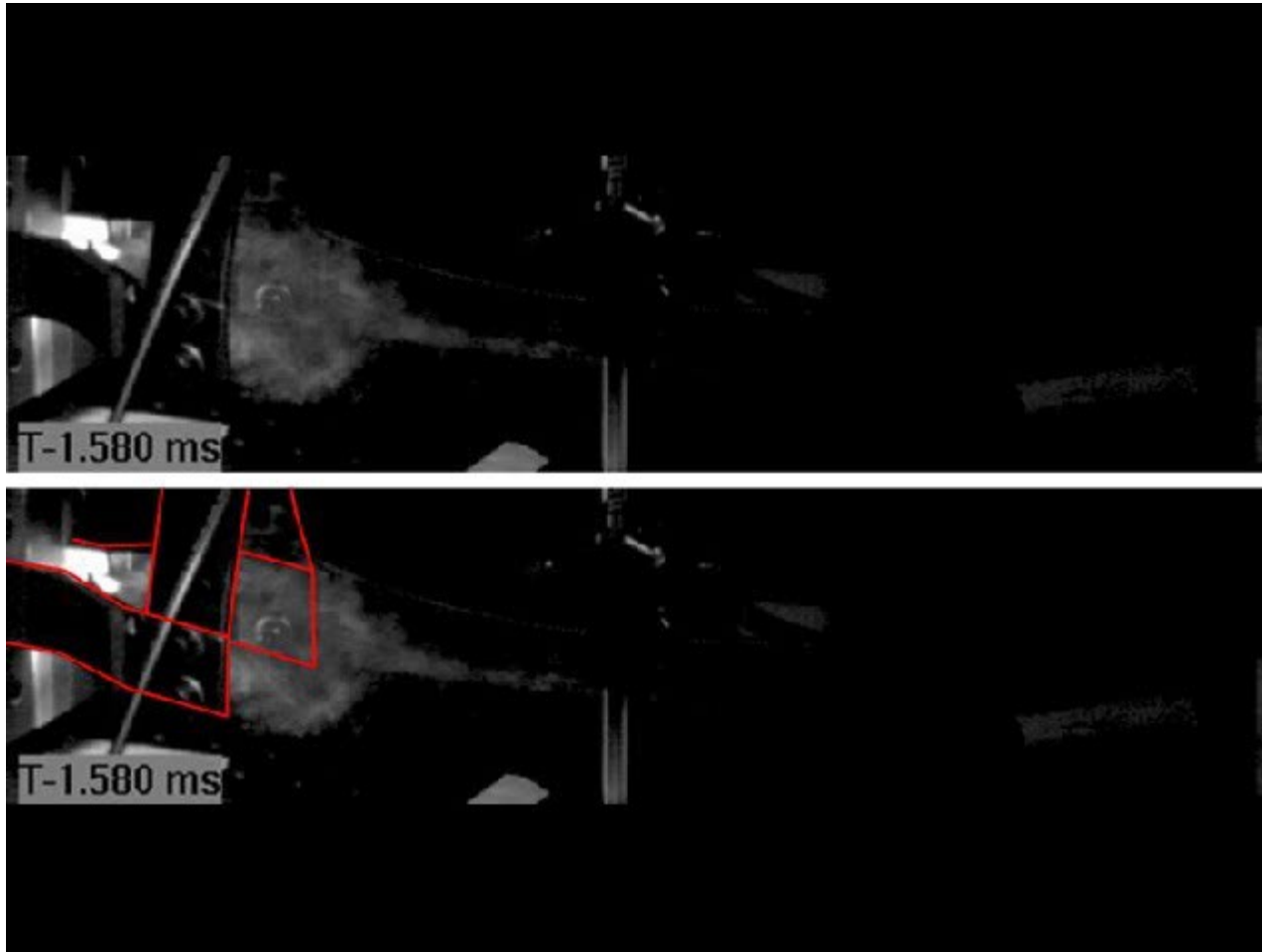
- Transient heating situations present a challenging class of problems for temperature diagnostics
- Approaches
  - Thin Film Thermocouples – require connection
  - Pyrometry – expensive/direct line of sight
  - Thermographic phosphors – film thickness dependent

# Areas of Application

- Micro and Nano devices
- High Pulse Current Devices eg. railguns



# Railgun Video - Transient Temperature Demonstration



# Approach



- How well does a phosphor layer follow a temperature that rises by 200 C over a period of about 15 ms?
- The purpose here is to examine the relationship between the thickness of a phosphor layer and how faithfully in time its temperature matches the temperature of the underlying surface.

# Modeling – Penetration Depth



$$l=4 \sqrt{\alpha t},$$

Where  $l$  is the penetration depth for a semi-infinite slab, the distance into the material to which heat penetrates in time  $t$ . ie.  $\Delta T \sim 99\%$ . (It is analogous to a boundary layer.)

Assuming  $\alpha$  is equivalent to glass:

$$l = 4\sqrt{(8 - 7m^2 / s)(15ms)} = 440\mu m.$$

# Modeling continued

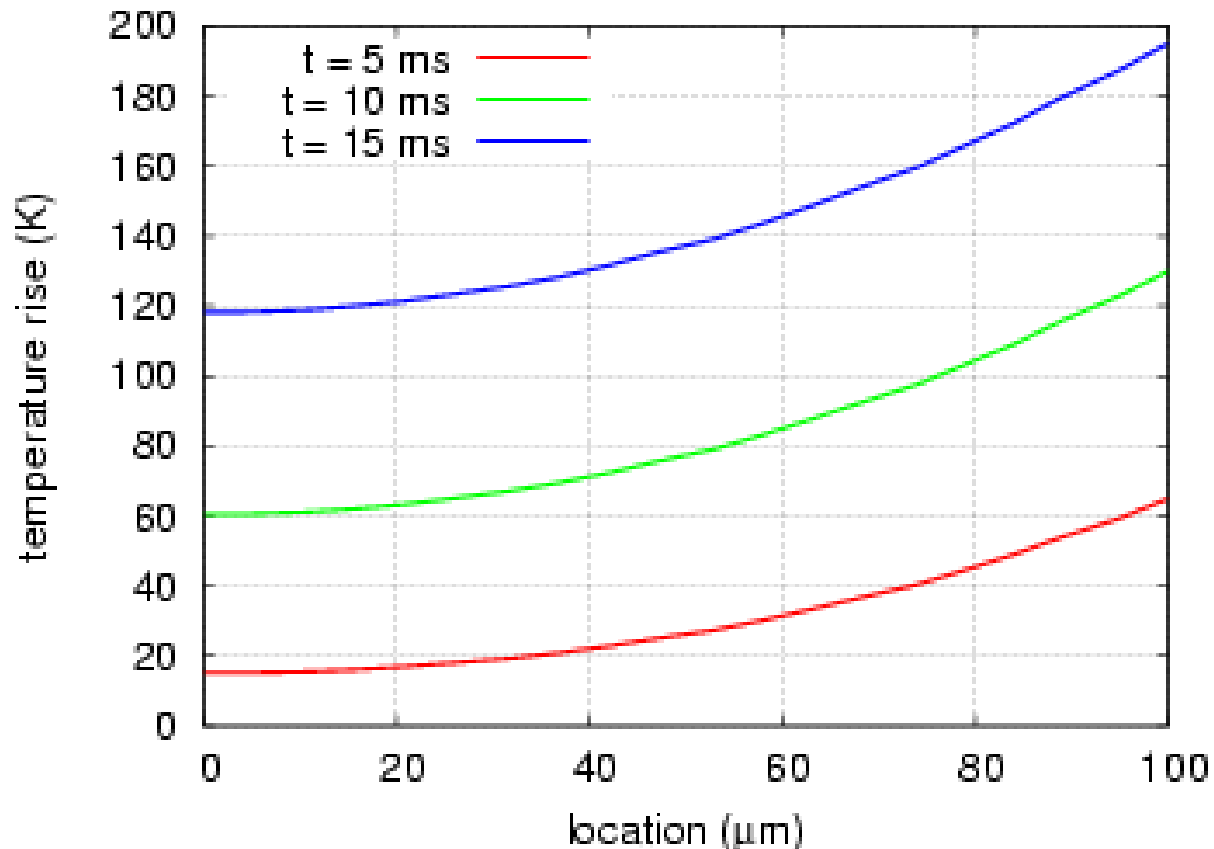


$$T(x, t) = \frac{2}{L} \sum_{n=0}^{\infty} \alpha \beta_n (-1)^n \exp(-\alpha \beta_n^2 t) \cos(\beta_n x) \int_0^t \phi(t') \exp(\alpha \beta_n^2 t') dt',$$

$T(x, t)$  is conduction solution where  $\phi(t) = \xi * t$  and  $\xi$  is the change in temperature per second

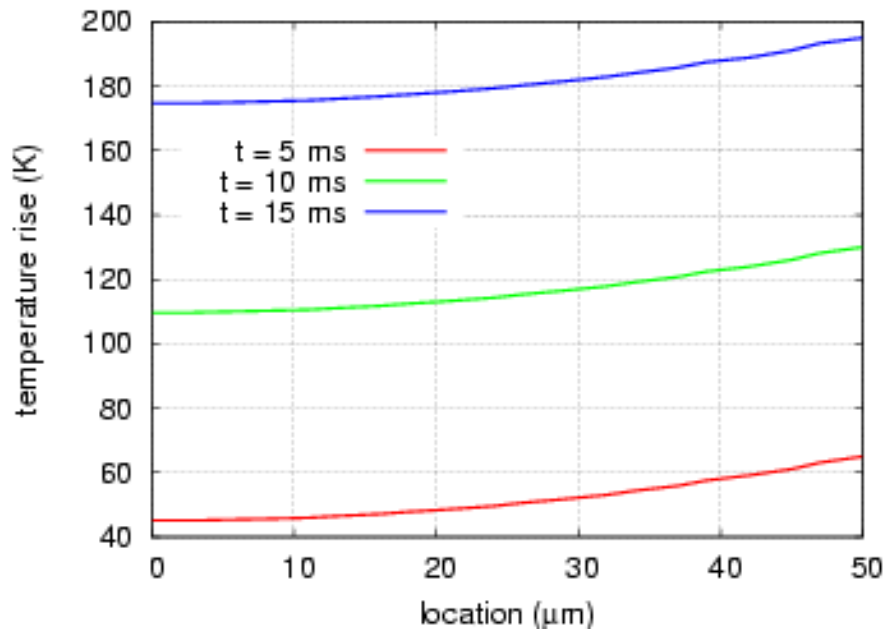
$$T(x, t) = \frac{2\xi}{\alpha L} \sum_{n=0}^{\infty} \frac{(-1)^n}{\beta_n^3} \cos(\beta_n x) [\alpha \beta_n^2 t - 1 + \exp(-\alpha \beta_n^2 t)]$$

If the armature heats up by 200K in 15ms, then the heating rate is  $\xi \gg 13,000K/s$ . The solution of latter equation is shown in the following figure.

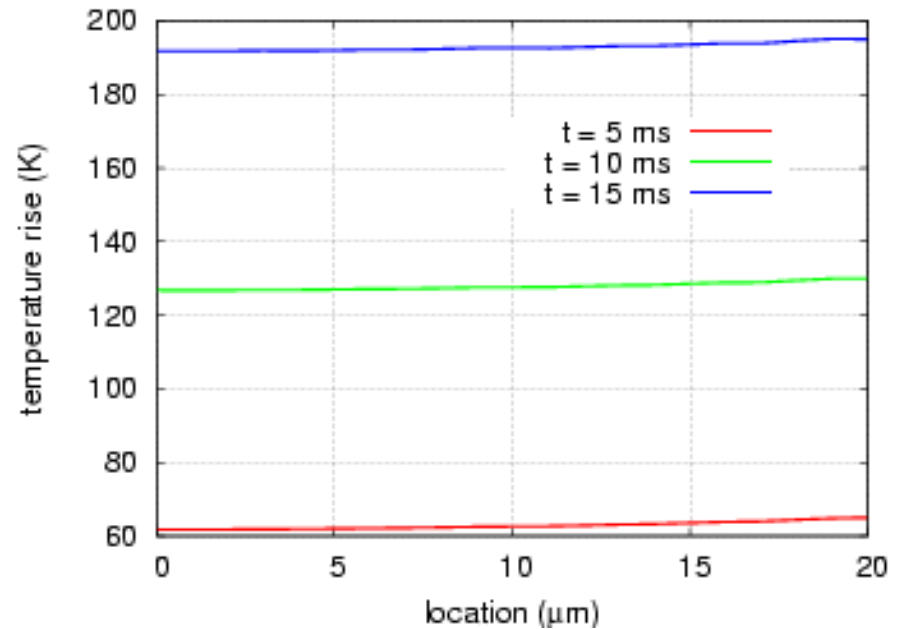


Temperature solution for a layer of phosphor being heated at  $x=100\mu\text{m}$ . The exposed surface is at  $x=0$

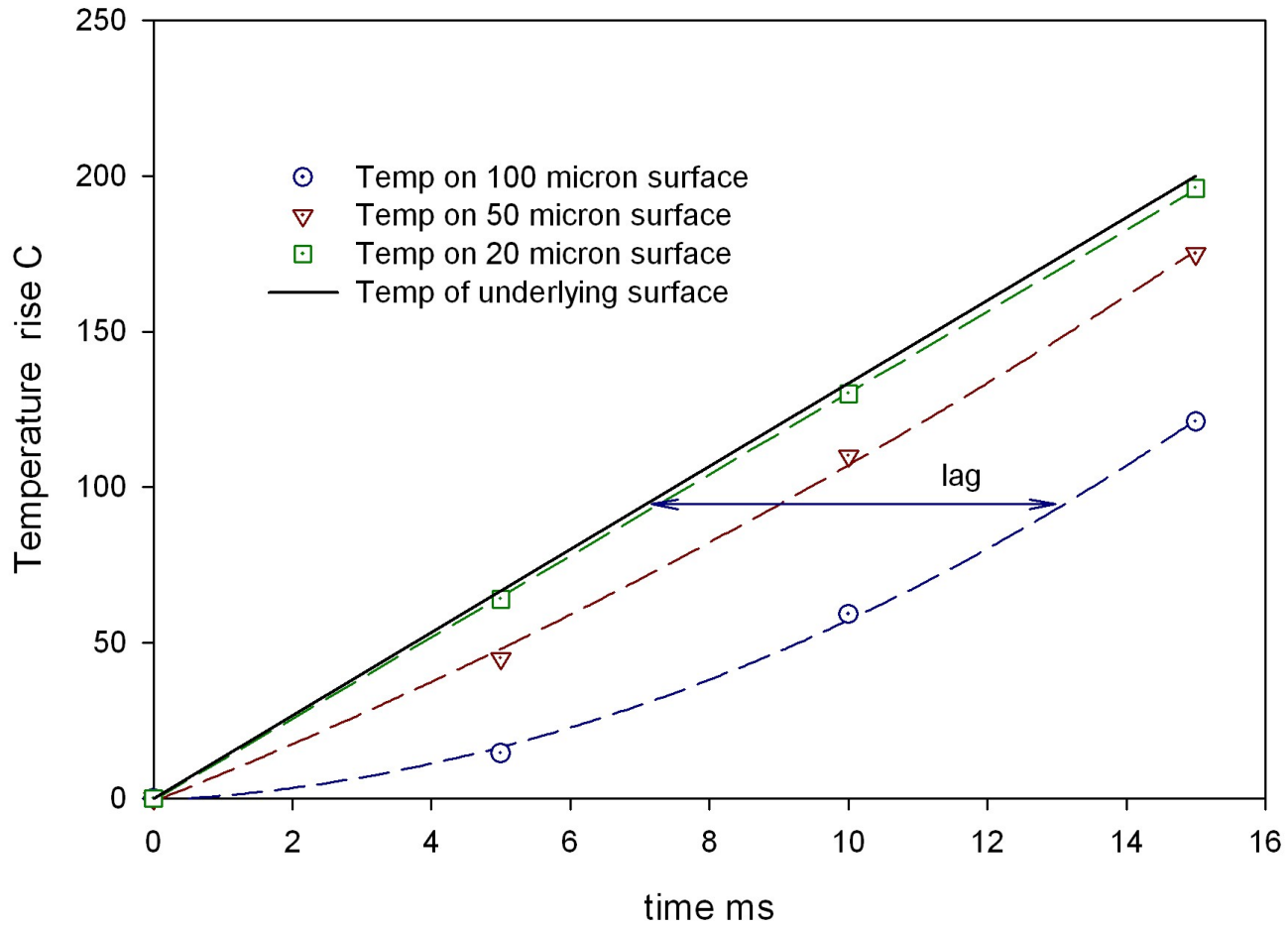
# 50 $\mu\text{m}$ and 20 $\mu\text{m}$ coating results



Temperature solution for a layer of phosphor being heated at  $x=50\mu\text{m}$ . The exposed surface is at  $x=0$ .



Temperature solution for a layer of phosphor being heated at  $x=20\mu\text{m}$ . The exposed surface is at  $x=0$ .



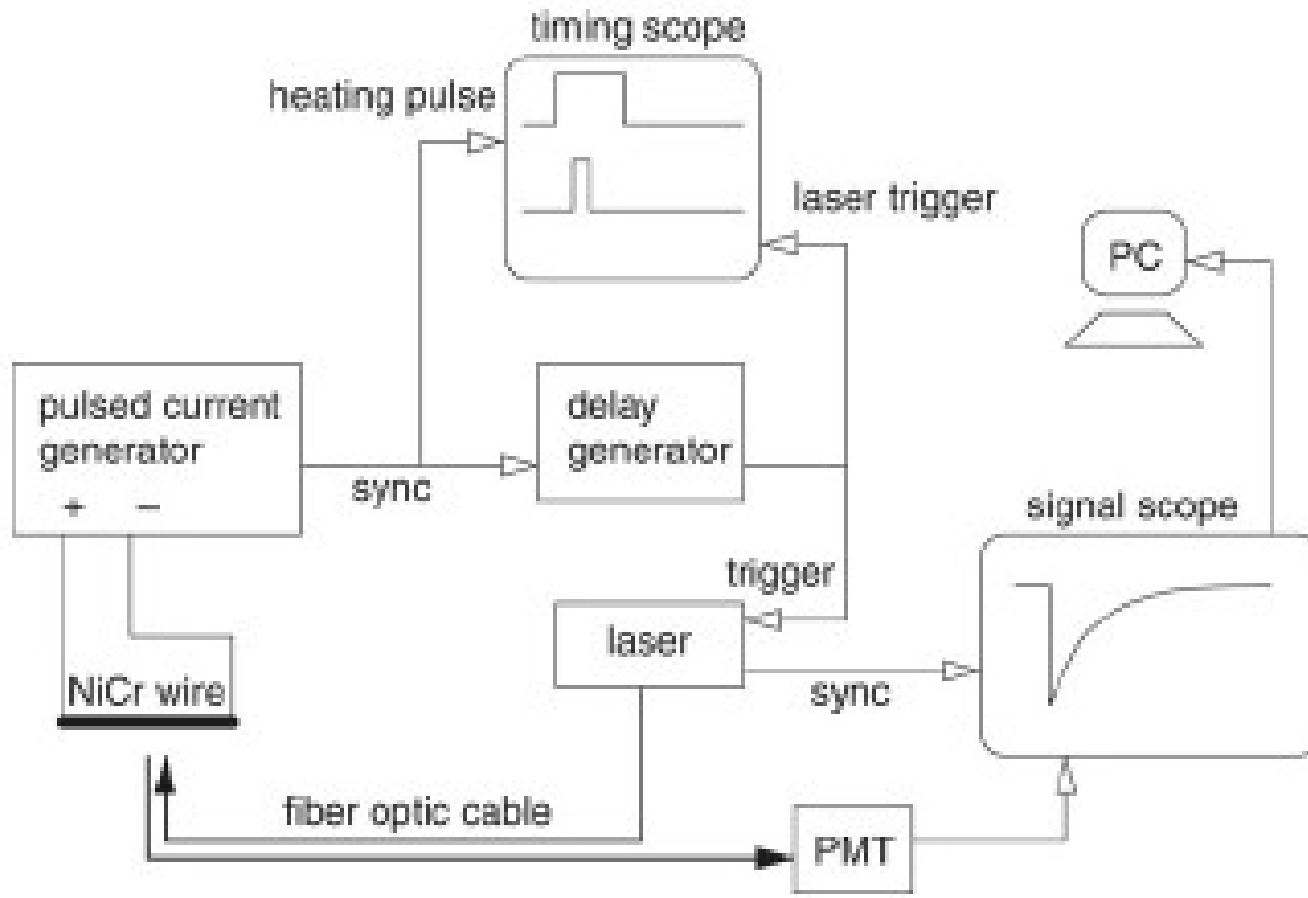
*Temperature of top layer vs thickness of layer.*

# Table of Results



Thickness	Top layer lag (ms)	$\Delta T$ top and bottom surface (C) at 200 C
20	1/3	-3
50	2	-25
100	6	-79

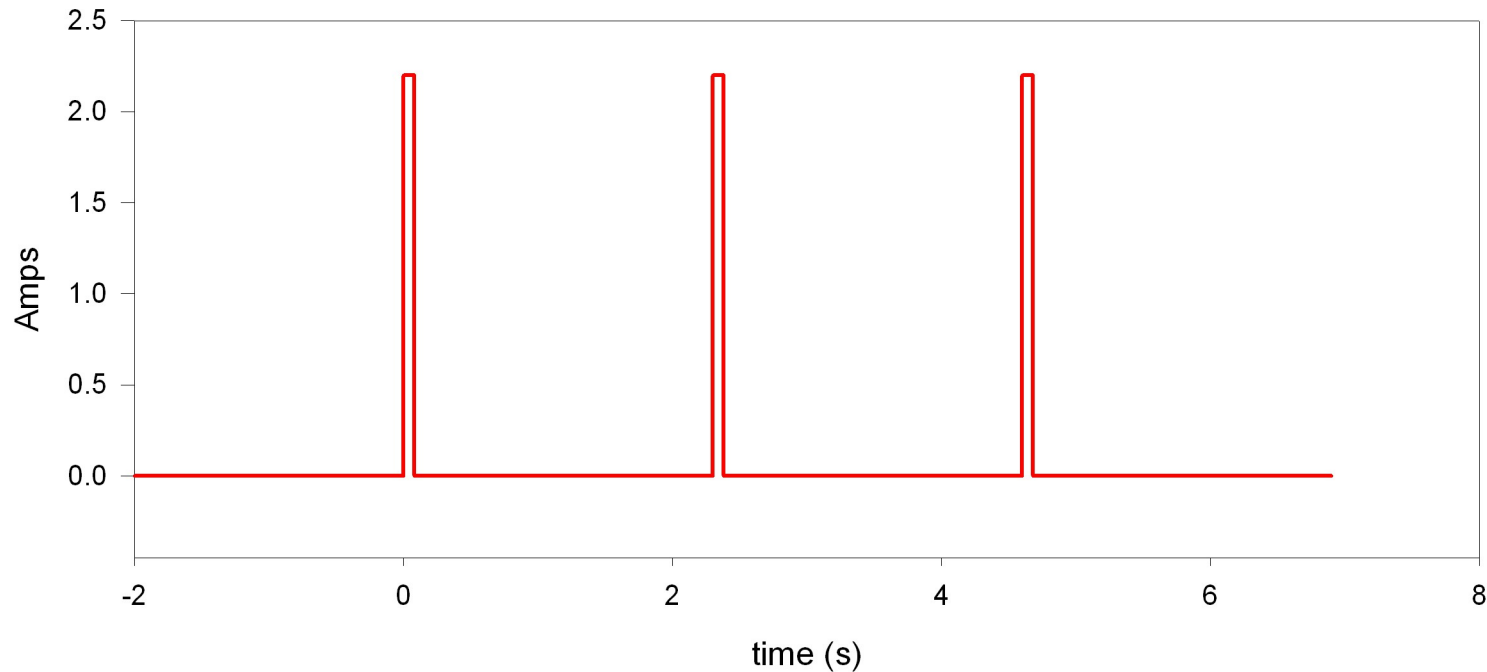
Nichrome wire coated with phosphor is a good laboratory test bed for producing rapid temperature changes.



# Periodic Current Applied to Nichrome

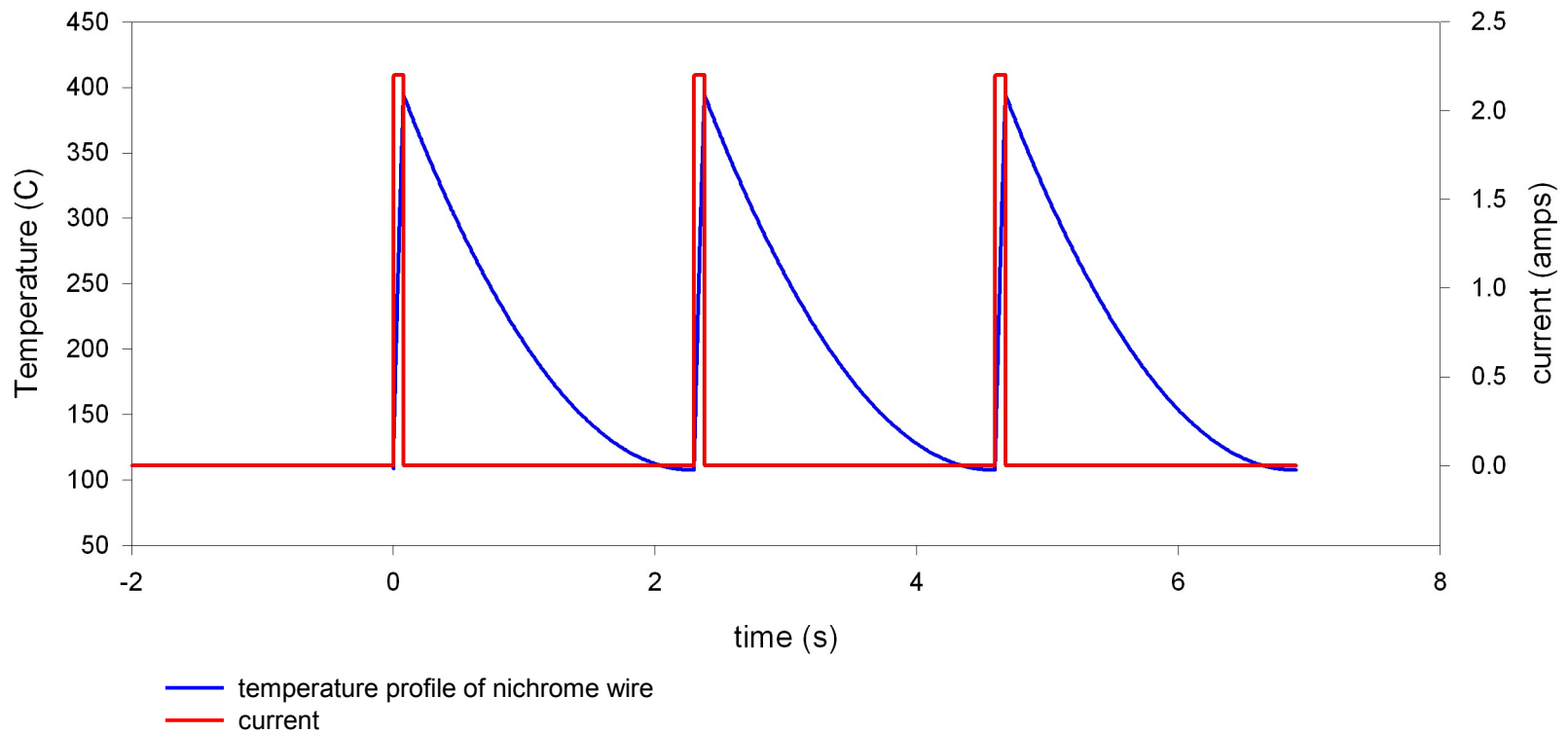


Nichrome Wire Heating

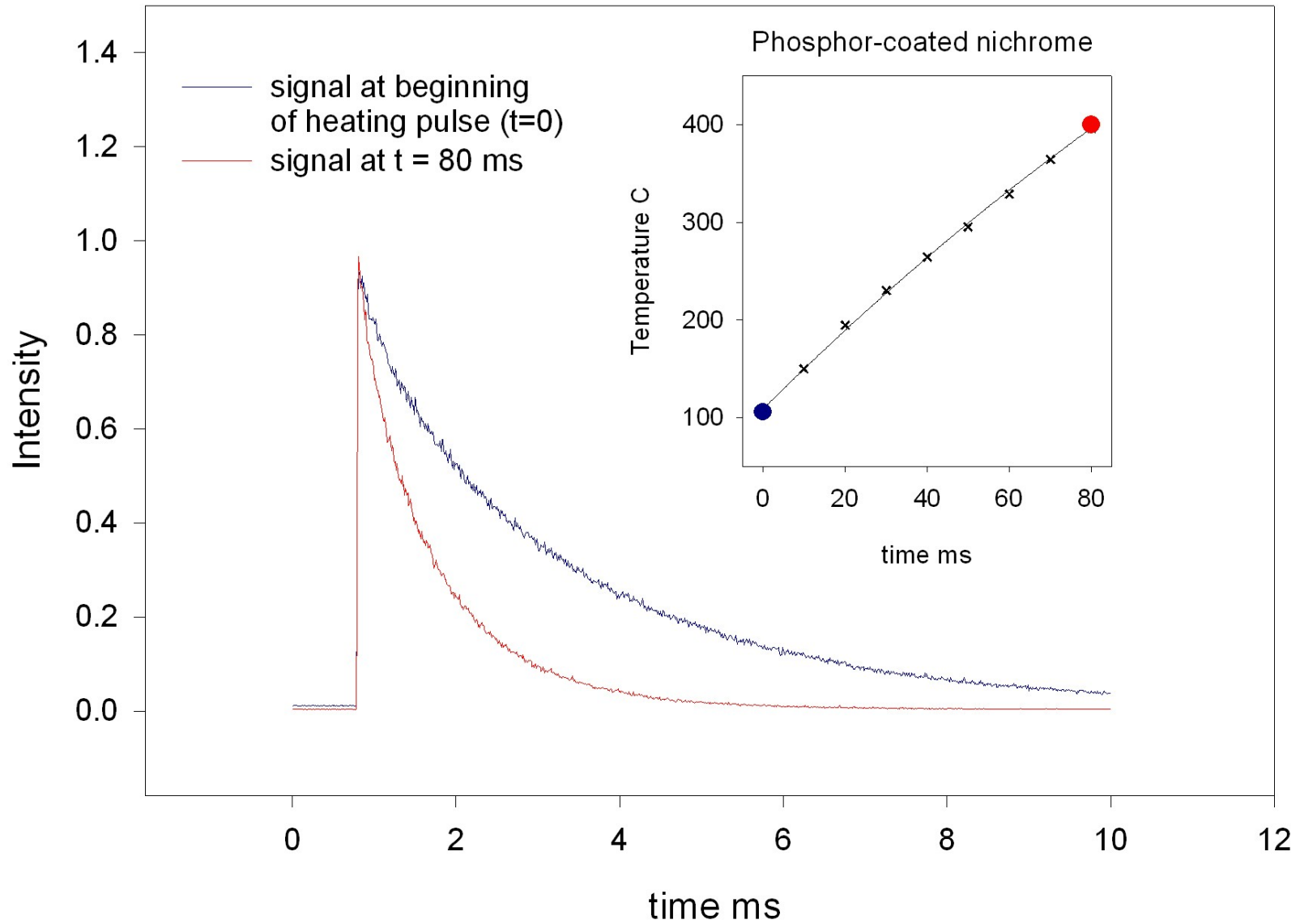


Square wave current impulse duration = 80 ms

## Nichrome Wire Heating and Temperature



300 C temperature swing 1560 cycles/hr



# Conclusions



- Nichrome wire test case shows 300 C rise in 80 ms.
- Given the difficulty of such measurements, the error associated with a 50 micron coating might be acceptable.
- After a sufficient lag time, the temperature rate of change is faithful regardless of coating thickness.
- It can be envisioned that the time lag could be an in situ thickness indicator.
- Clearly more detailed and rigorous analysis is desirable and the present work is another step toward that goal.

# References



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