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Analysis of Transient Heating of Phosphor Coatings

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Steve Allison

- 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

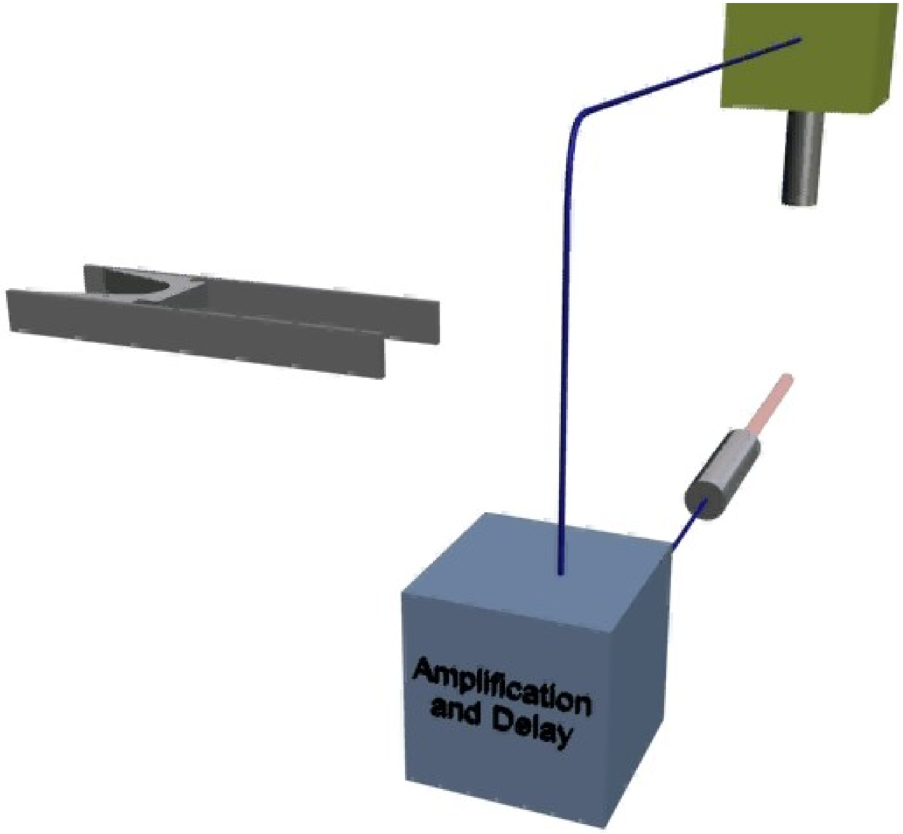
Justification

- Transient heating situations present a challenging class of problems for temperature diagnostics

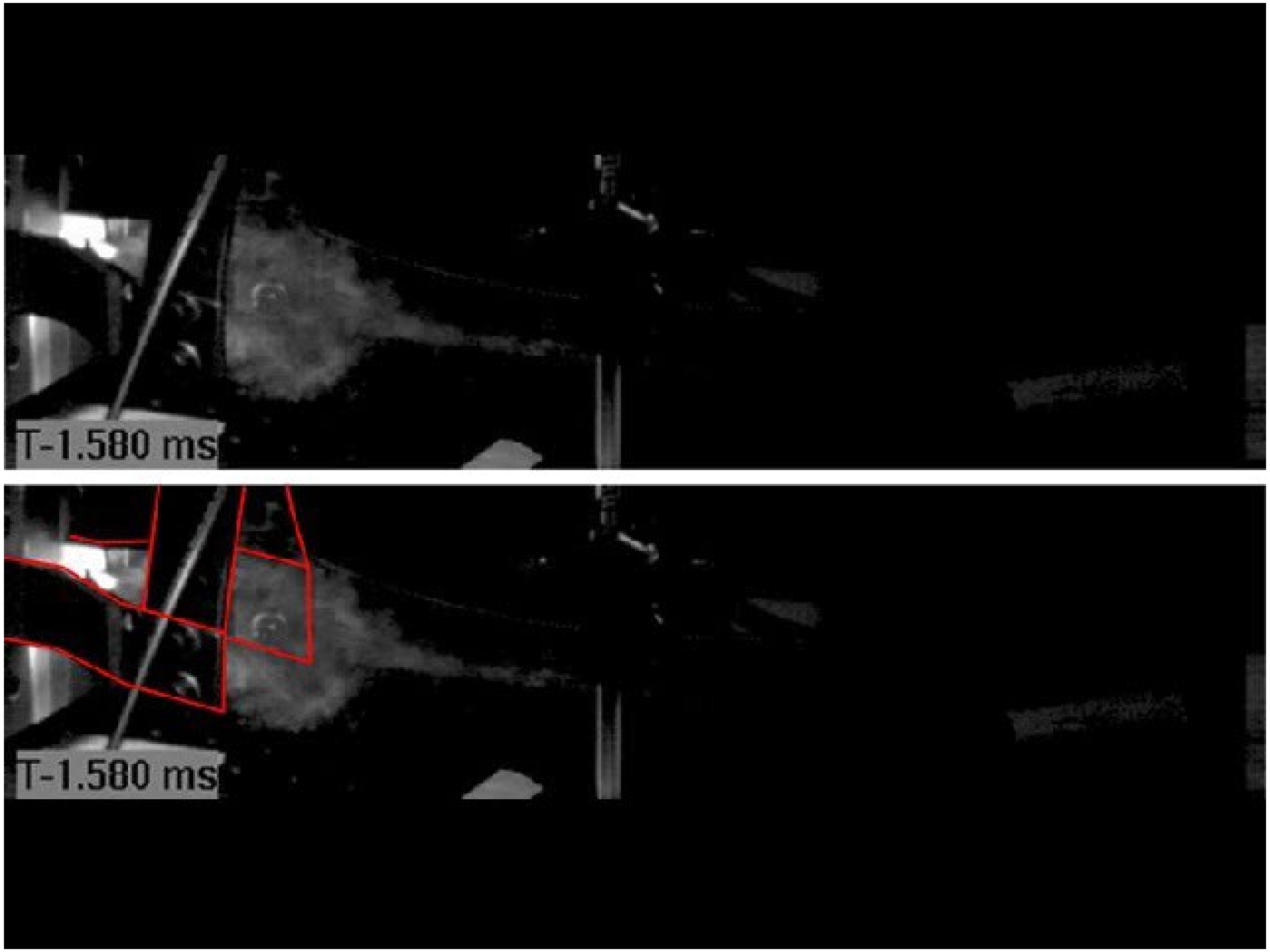
- Approaches
  - Thin Film Thermocouples – require connection
  - Pyrometry – expensive/direct line of sight
  - Thermographic phosphors – film thickness dependent

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. Δ T~99% . (It is analogous to a boundary layer.)

Assuming α is equivalent to glass:

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

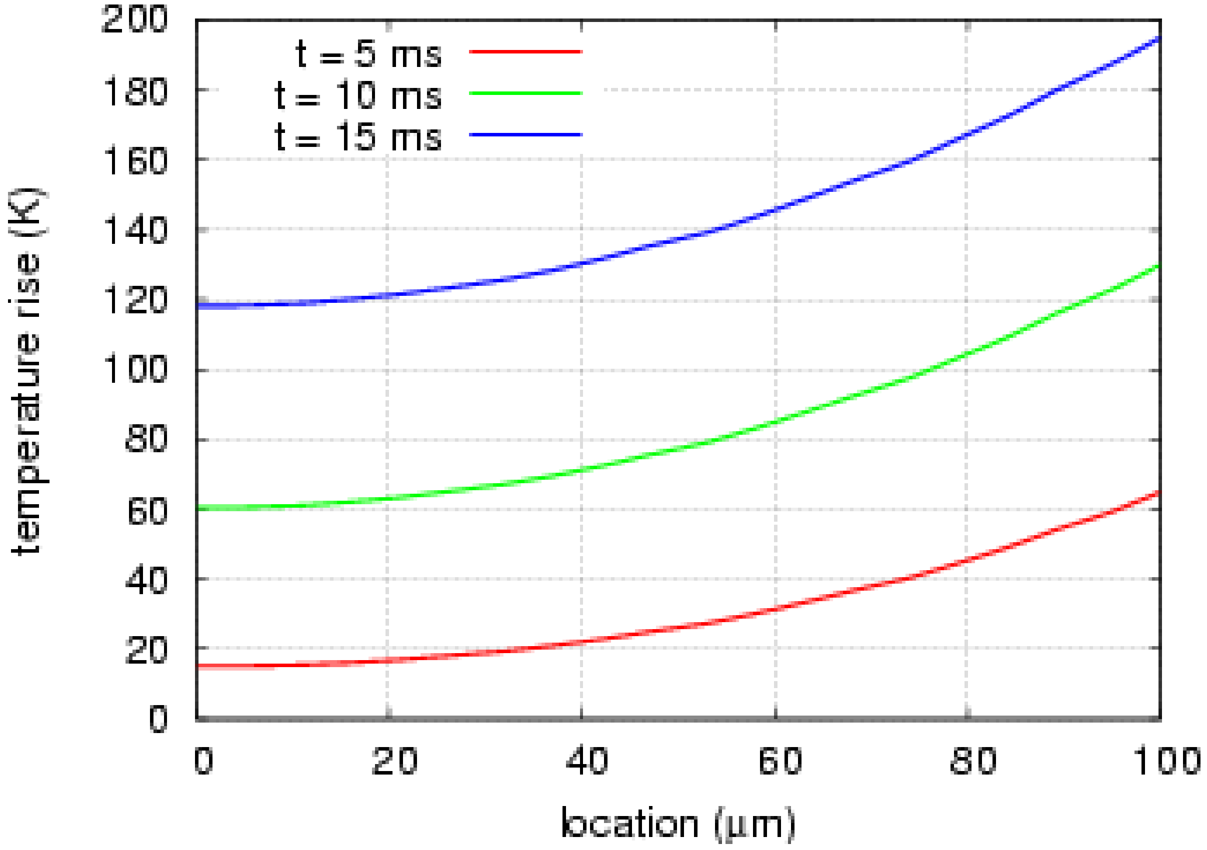
Modeling continued

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

T(x,t) is conduction solution where φ(t)=ξ*t and ξ is the change in temperature per second

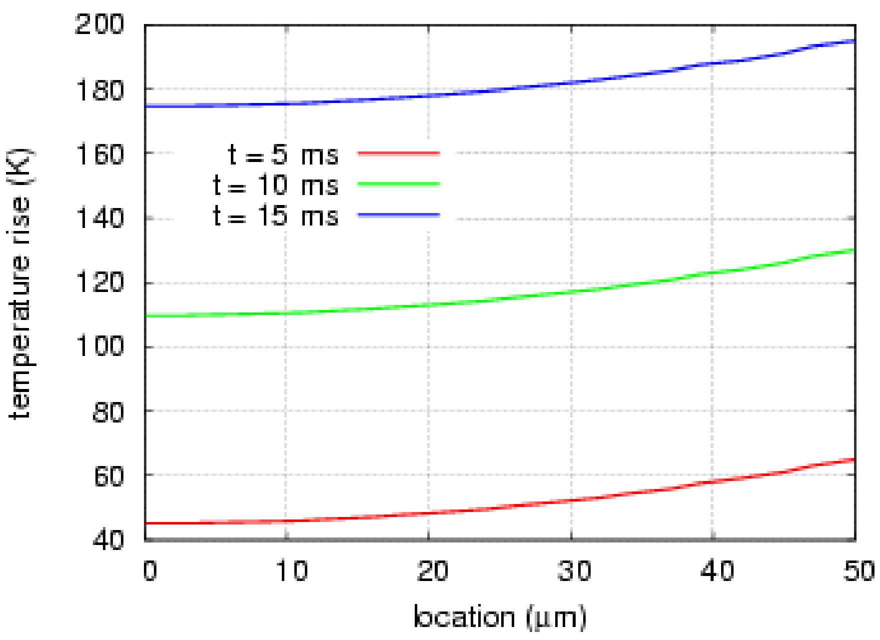
$$T(x,t) = \frac{2\xi}{\alpha L}\sum_{n=0}^{\infty} \frac{(-1)^n}{\beta_n^3}\cos\left(\beta_n x\right)\left[\alpha\beta_n^2 t - 1 + \exp\left(-\alpha\beta_n^2 t\right)\right]$$

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

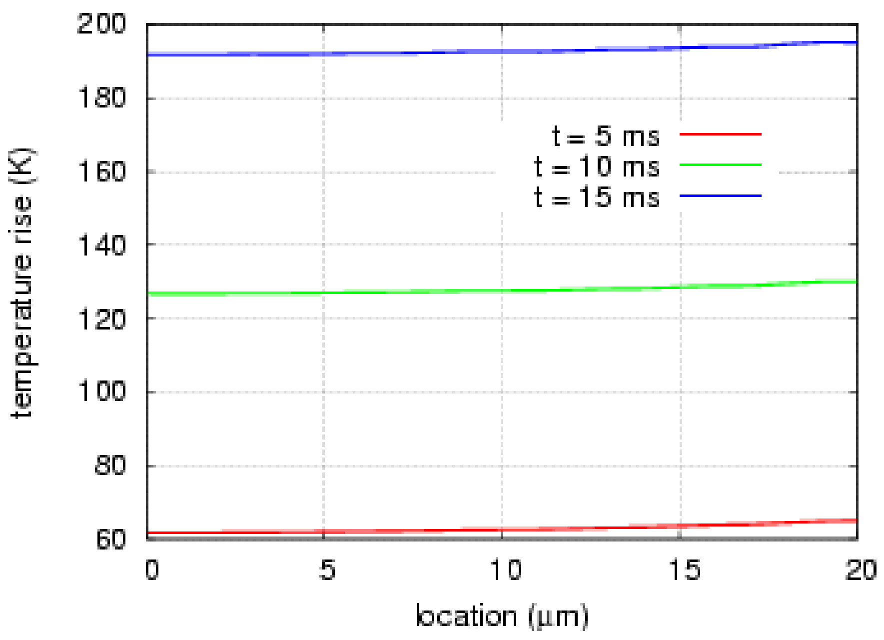


Temperature solution for a layer of phosphor being heated at x=100μm. The exposed surface is at x=0

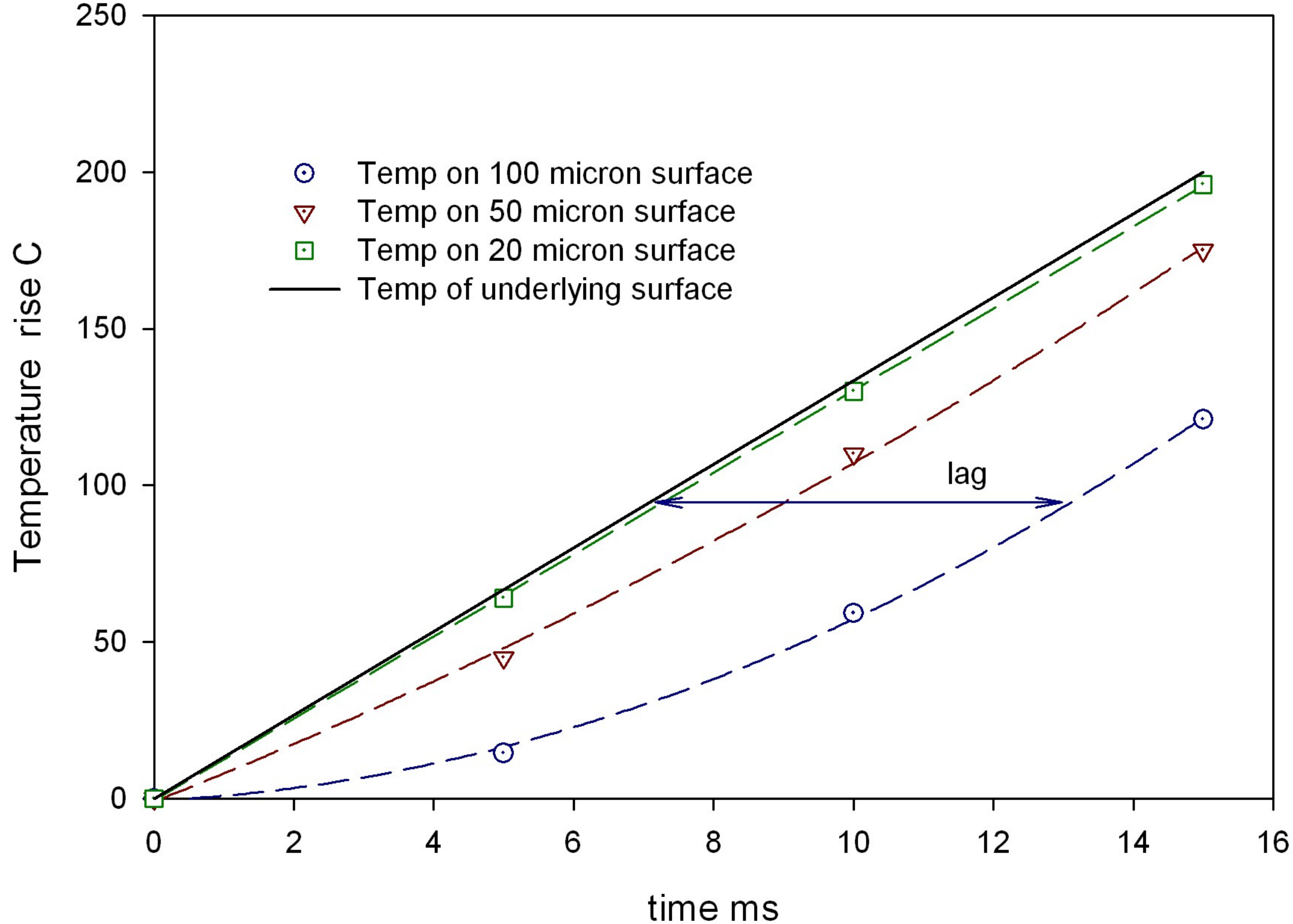
50 µm and 20 µm coating results



Temperature solution for a layer of phosphor being heated at x=50µ*m*. The exposed surface is at x=0.



Temperature solution for a layer of phosphor being heated at x=20µ*m*. The exposed surface is at x=0.

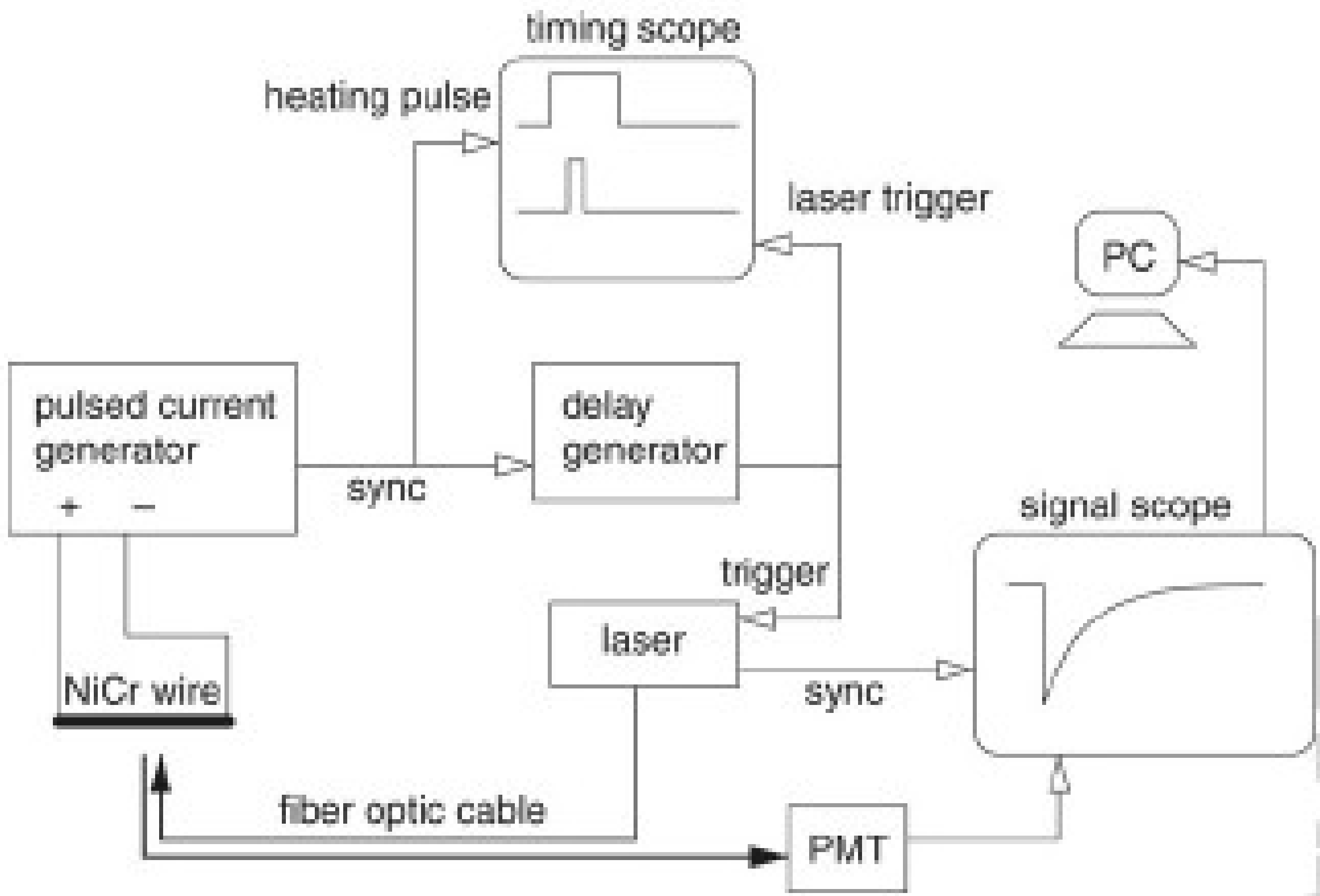


Temperature of top layer vs thickness of layer.

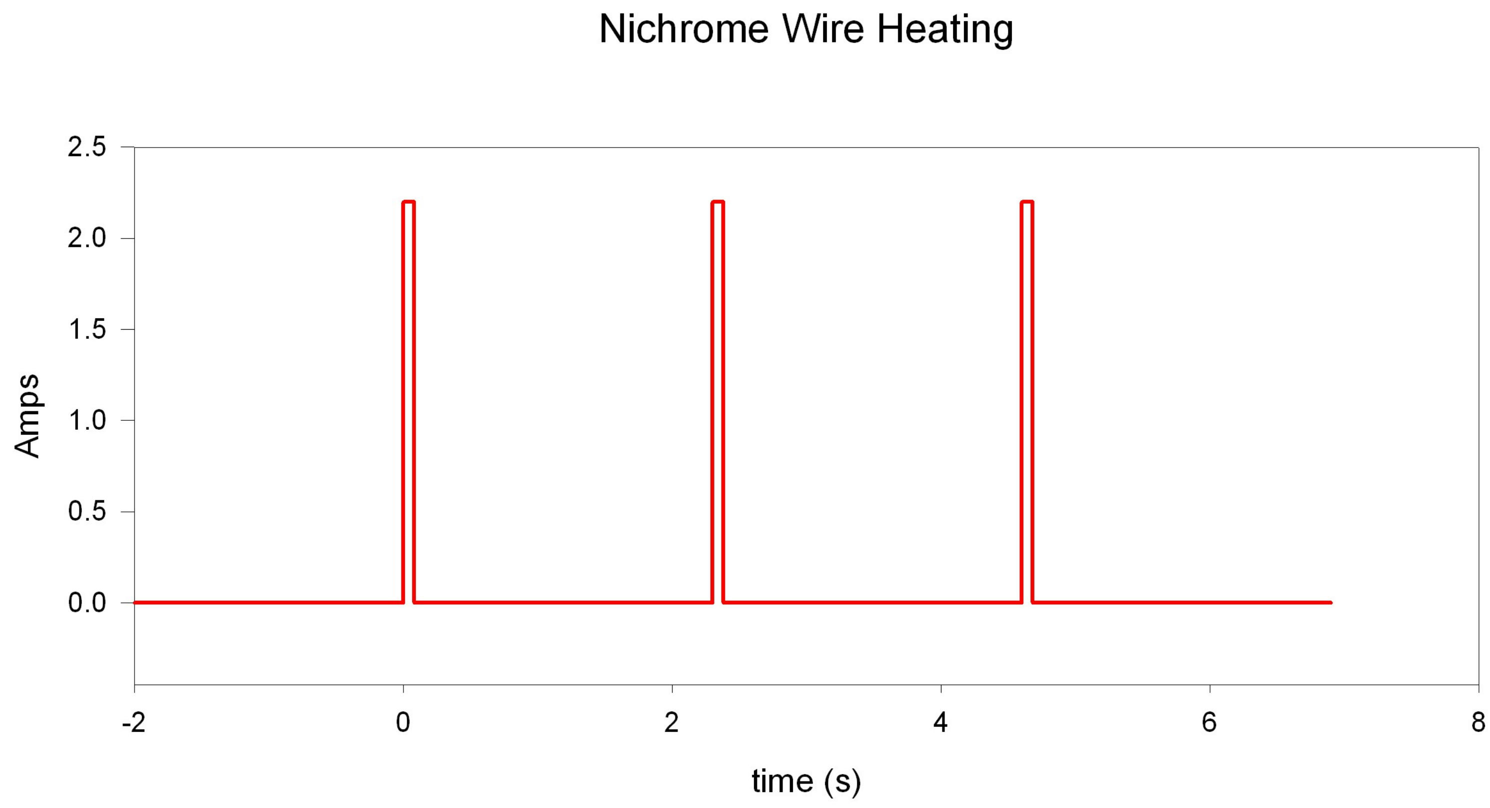
Table of Results

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

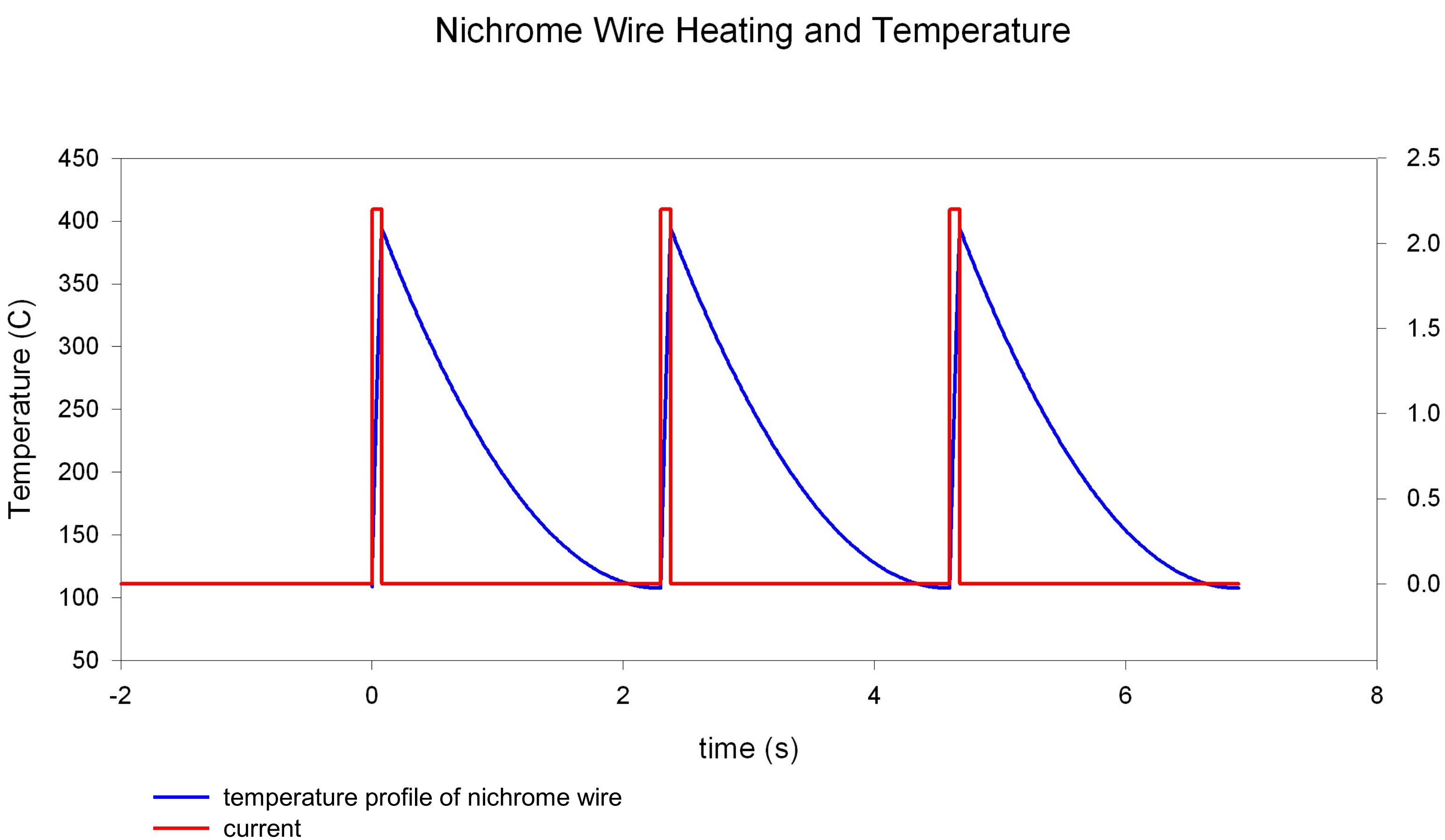
Nichrome wire coated with phosphor is a good laboratory test bed for producing rapid temperature changes.



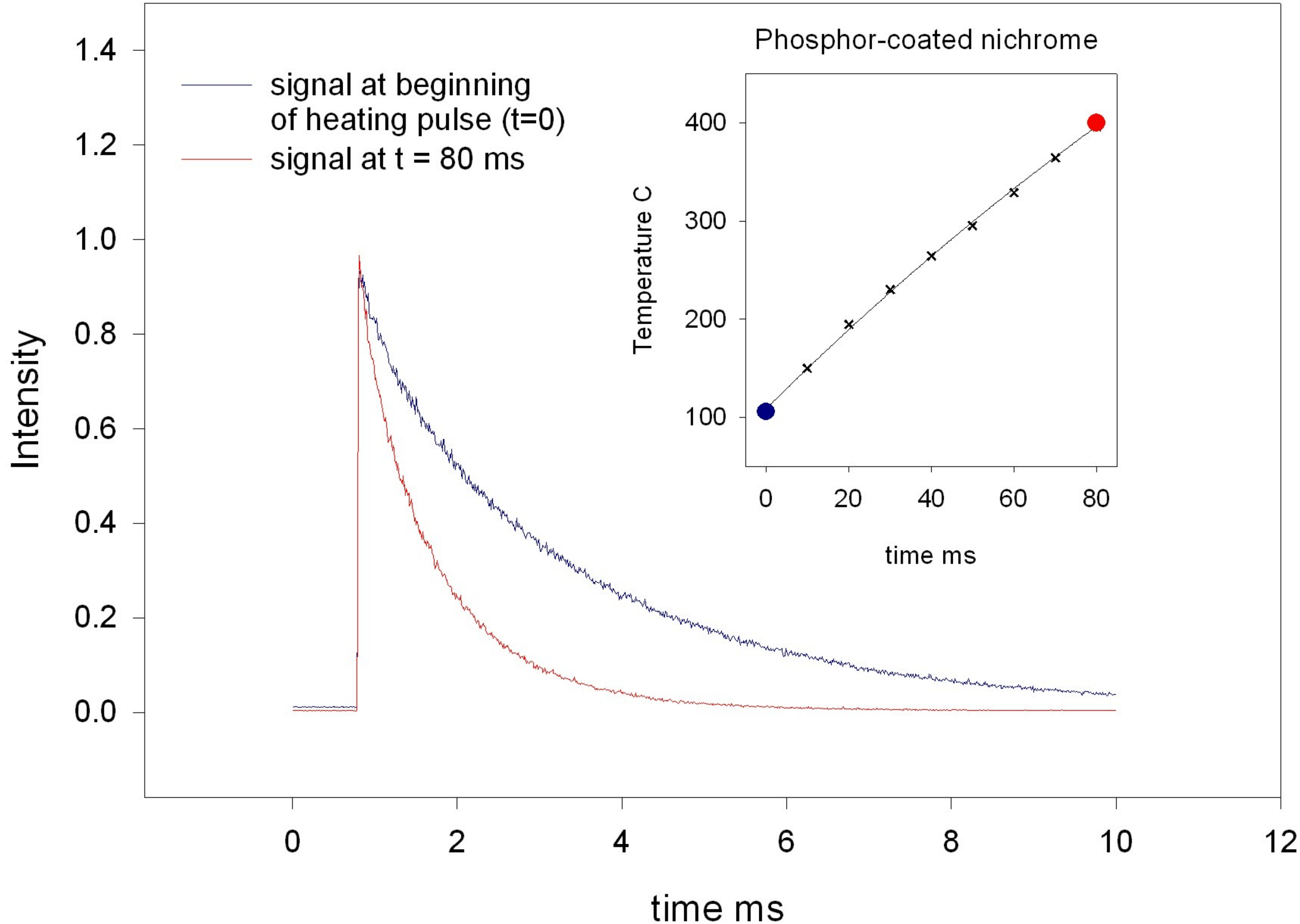
Periodic Current Applied to Nichrome



Square wave current impulse duration = 80 ms



300 C temperature swing 1560 cycles/hr



Phosphor-coated nichrome
signal at beginning
of heating pulse (t=0)
signal at t = 80 ms
Intensity
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12
time ms
Temperature C
400
300
200
100
0
20
40
60
80
time ms

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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