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Transient Thermal Stability of Polymer Nanocomposites

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U.S. Army ARDEC – Benet Laboratories
DOD Multifunctional Materials for Defense 2012

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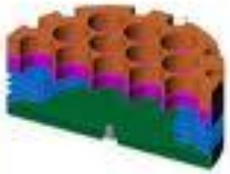
Motivation

Composites

Weapon Systems/Components

Energy Transduction



Motivation

Nanocomposite properties

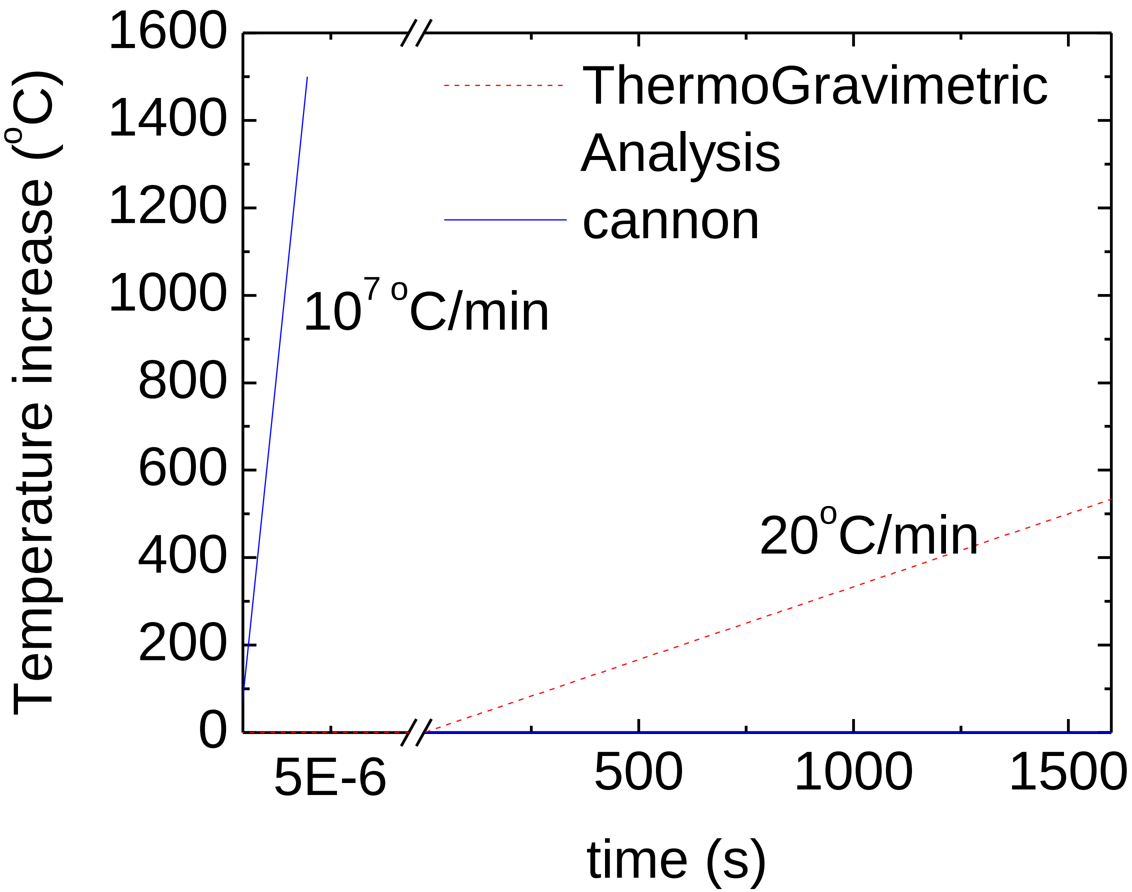
- Lightweight
- Inexpensive
- Processible
- Good mechanical properties

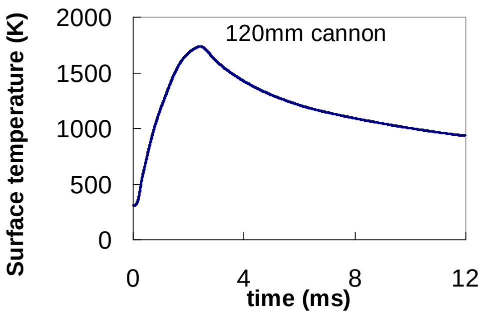
DoD applications

- Weapon systems
- Components
- Munitions
- High-frequency high-voltage switching

Bridging this gap requires understanding the kinetics of degradation under transient thermal loading

Transient Heating



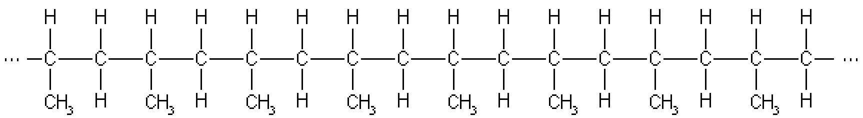


Six orders of magnitude difference in heating rate

Goal of this project

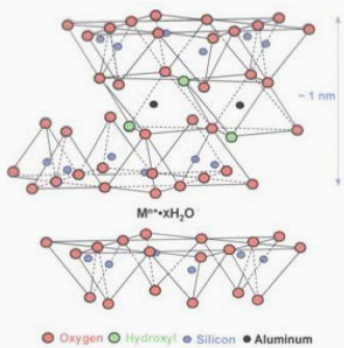
Use polypropylene as a model system to investigate degradation kinetics during transient heating

Materials



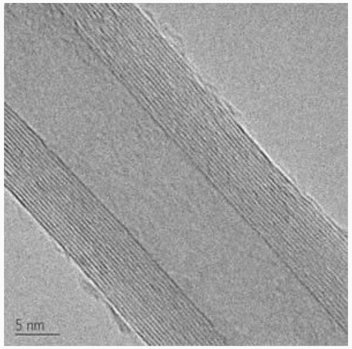
Isotactic Polypropylene

+



0-50 wt % nanoclay (modified Montmorillonite, Nanocor masterbatch)

$(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2 \cdot nH_2O$

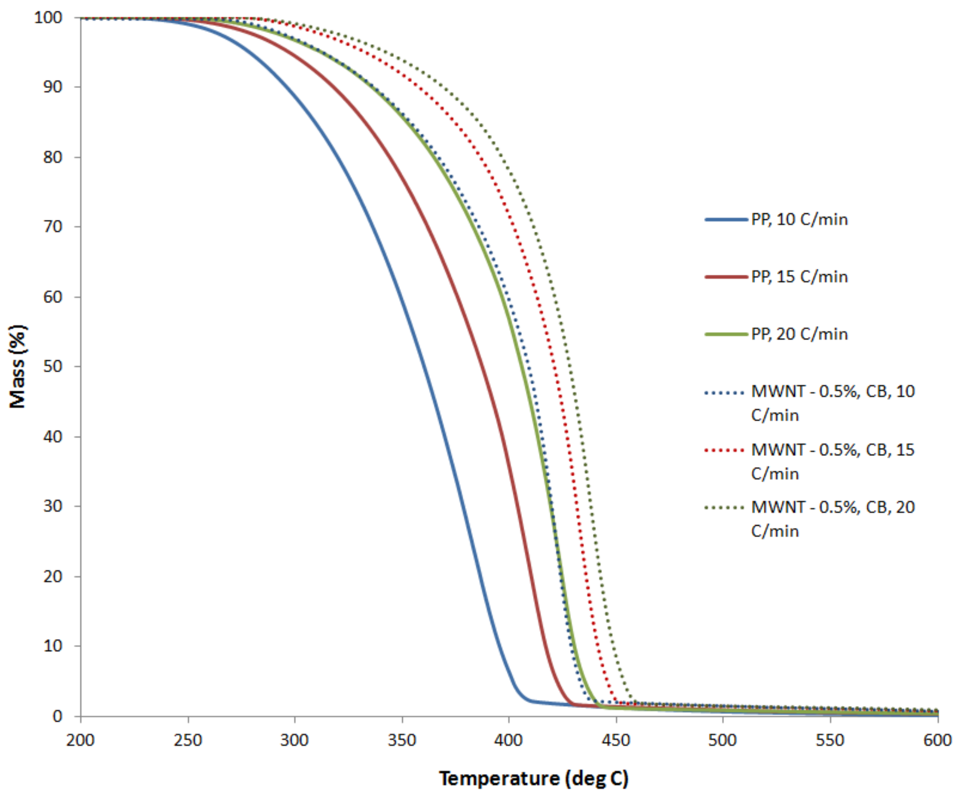


Multiwalled Carbon Nanotubes (Nanocyl masterbatch)

1 wt % carbon black

Twin screw extrusion (190C)

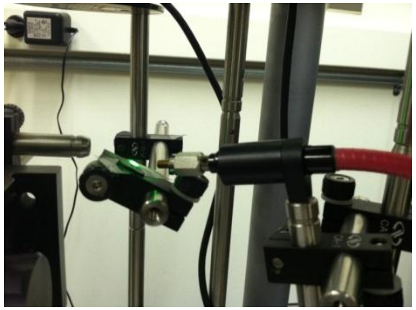
Slow Heating Regime

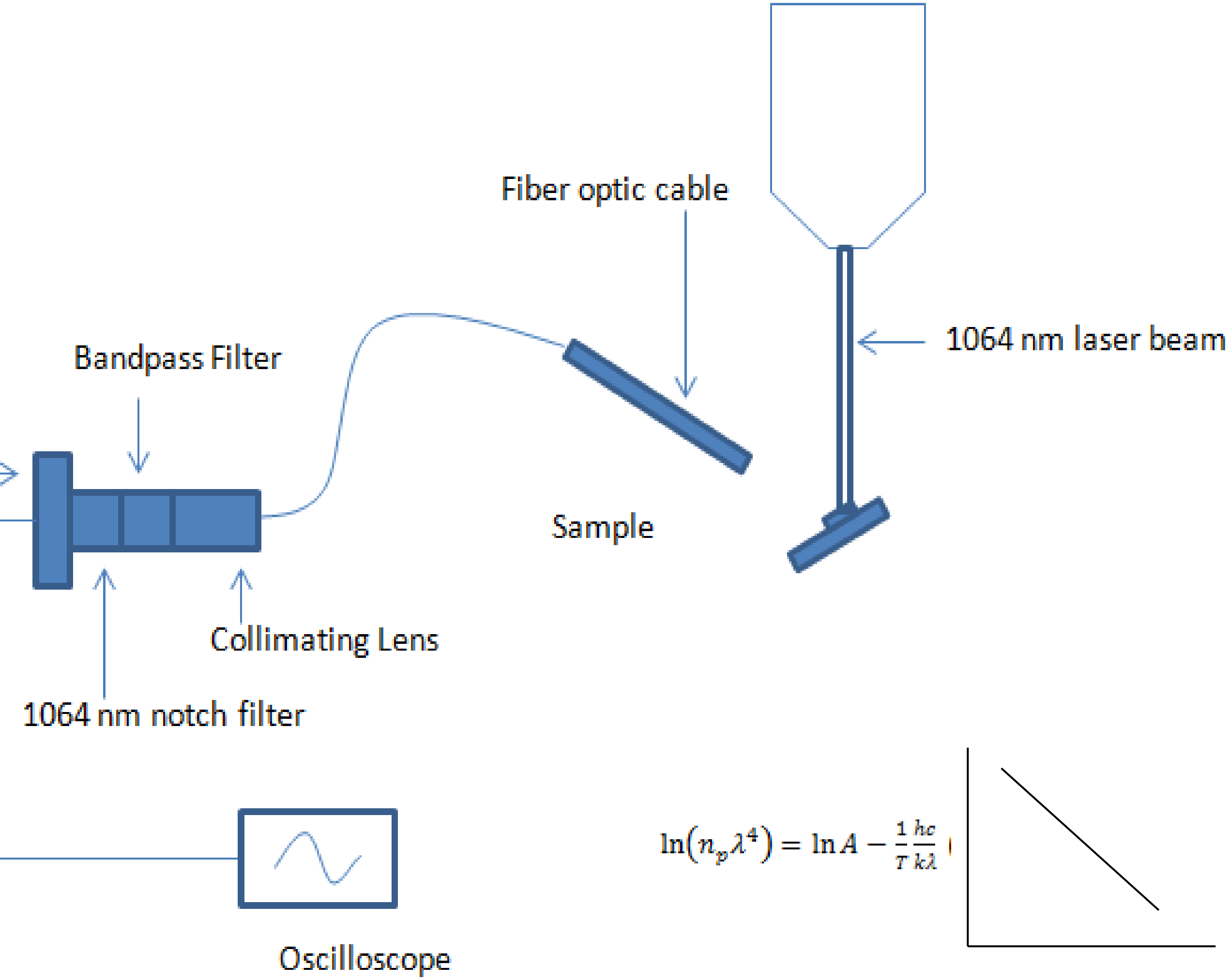


Thermogravimetric Analysis

Nanospecies improve thermal stability as expected

Laser pulse heating



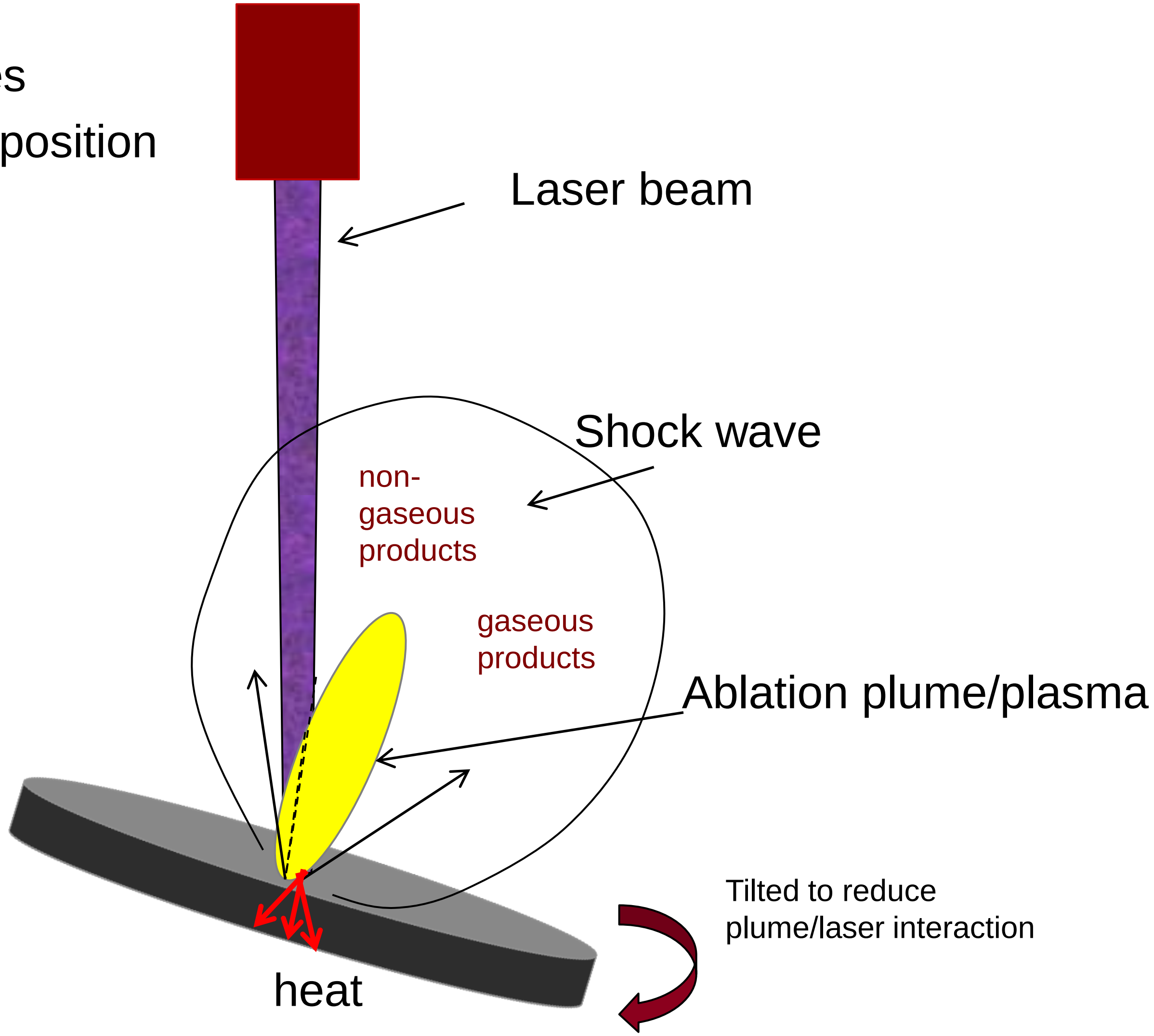


$$\ln(n_p\lambda^4) = \ln A - \frac{1}{T}\frac{hc}{k\lambda}$$

Laser pulse heating

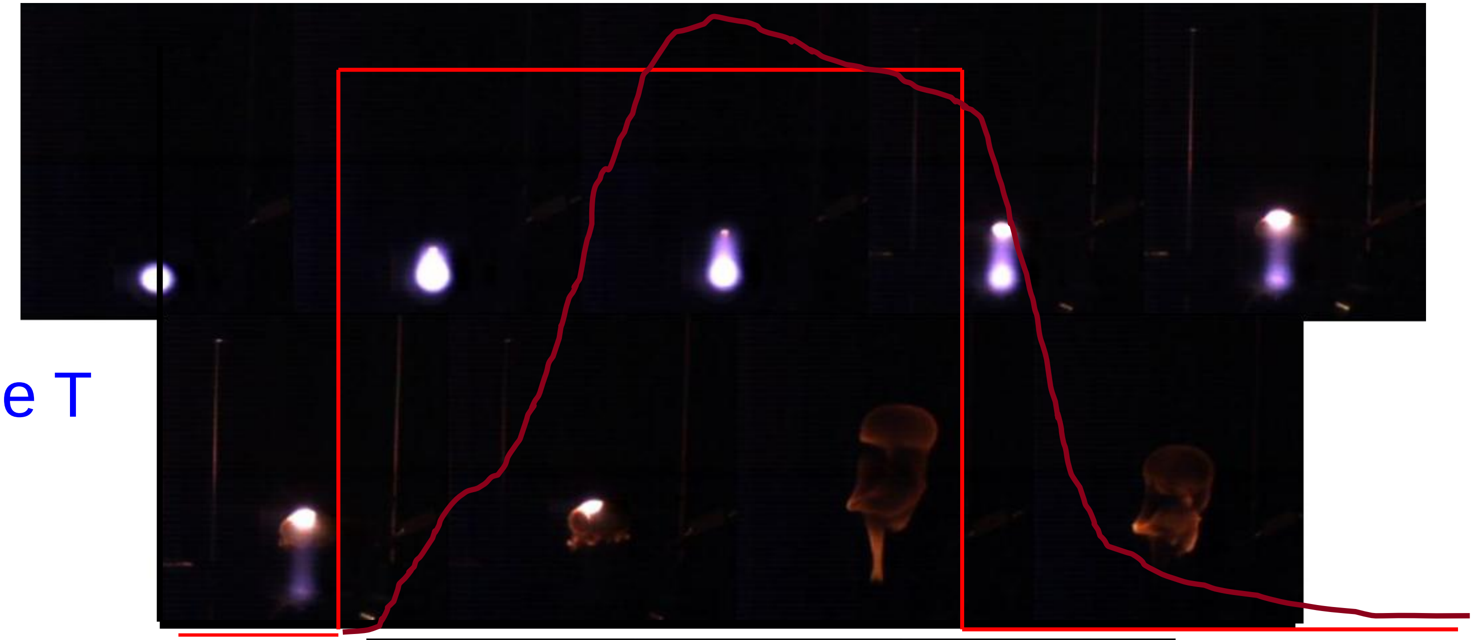
Photothermal processes

⟶ Thermal decomposition



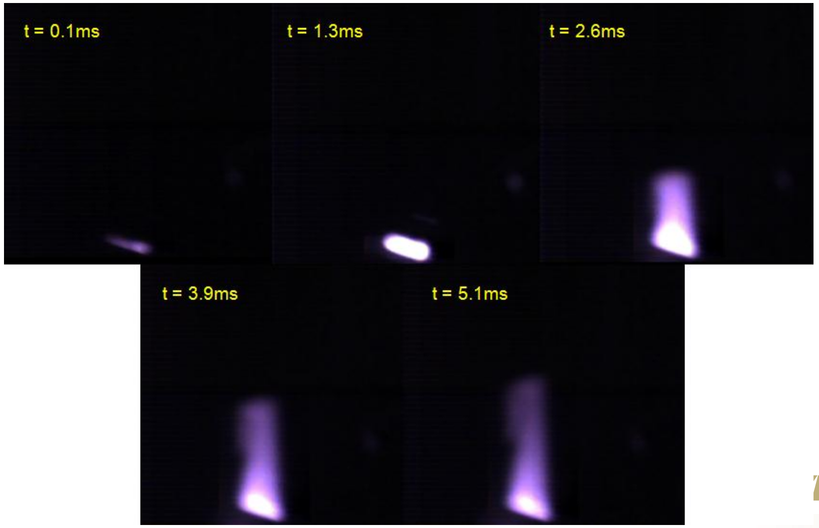
Real-time monitoring of irradiation

High Speed Videos

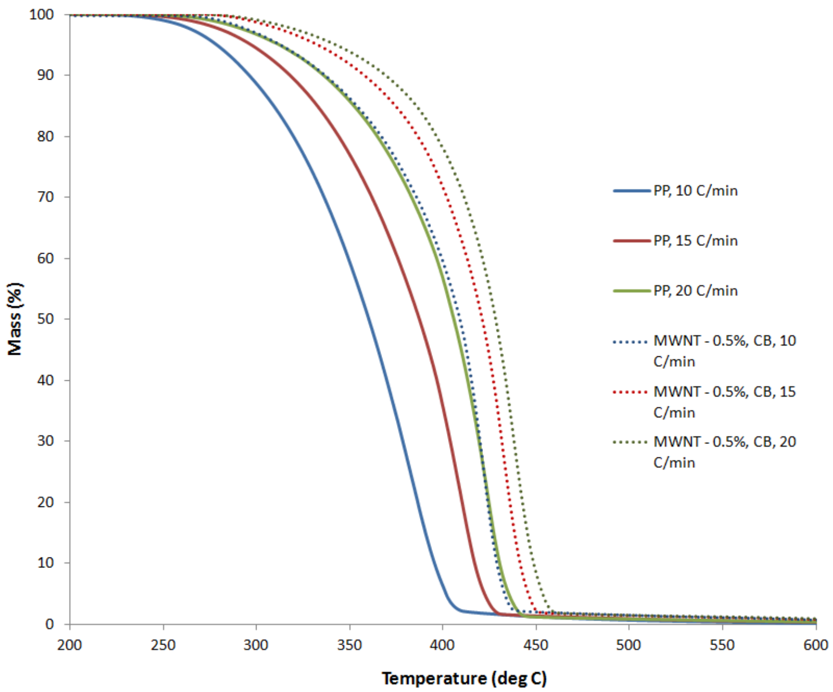


Surface T cools

Surface T plateau



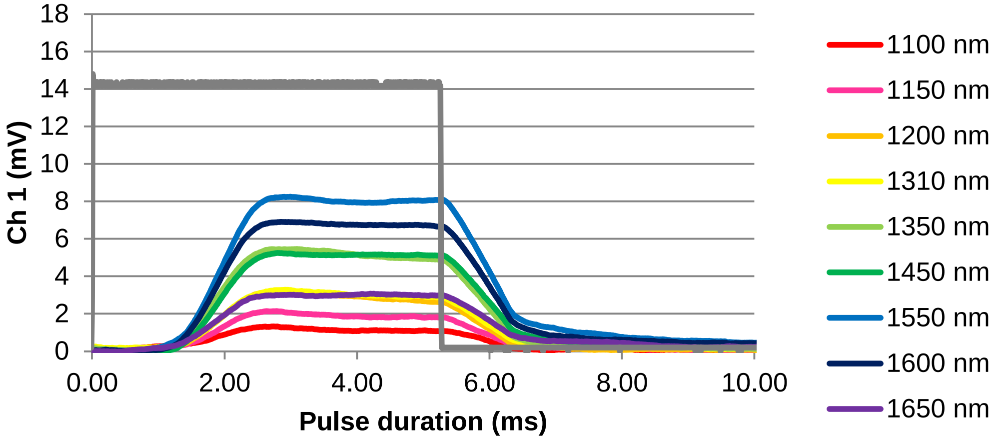
Thermogravimetric Analysis



$$\frac{dC}{dT} = \frac{A}{\beta} f(C) e^{-\frac{E}{RT}}$$ ← Obtain activation energy

Temperature Measurements

1. Measure emitted photopower at varying λ



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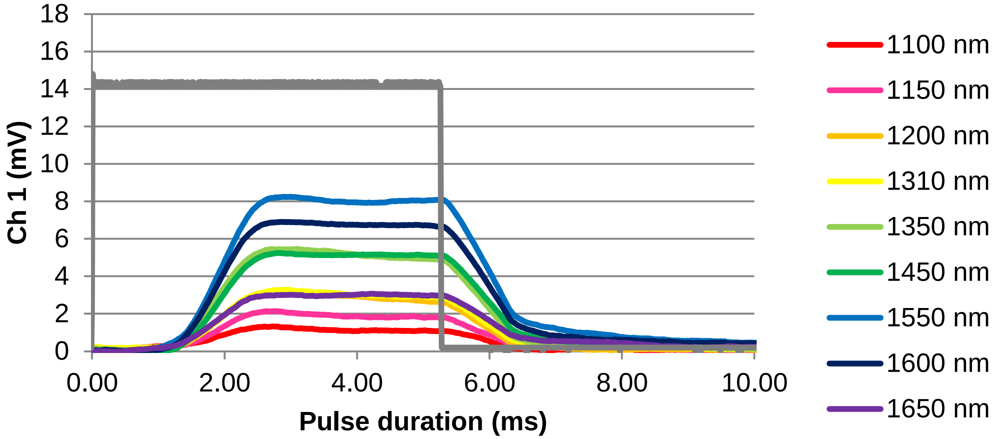
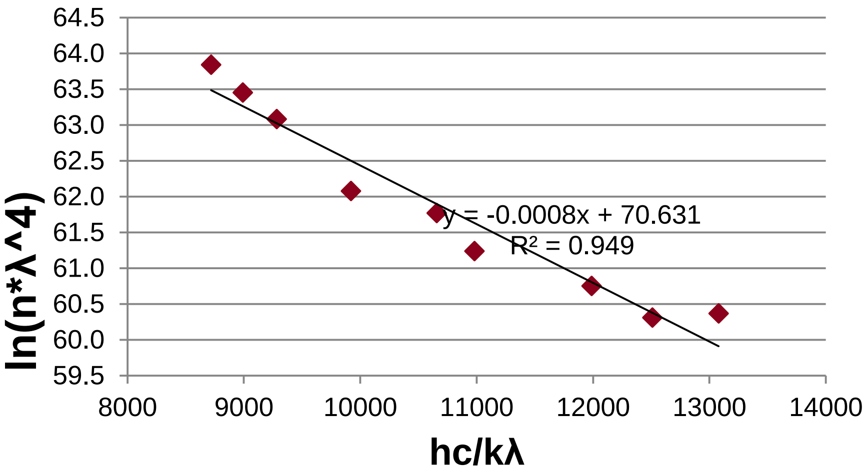


2. Fit to Planck's Law at each time step



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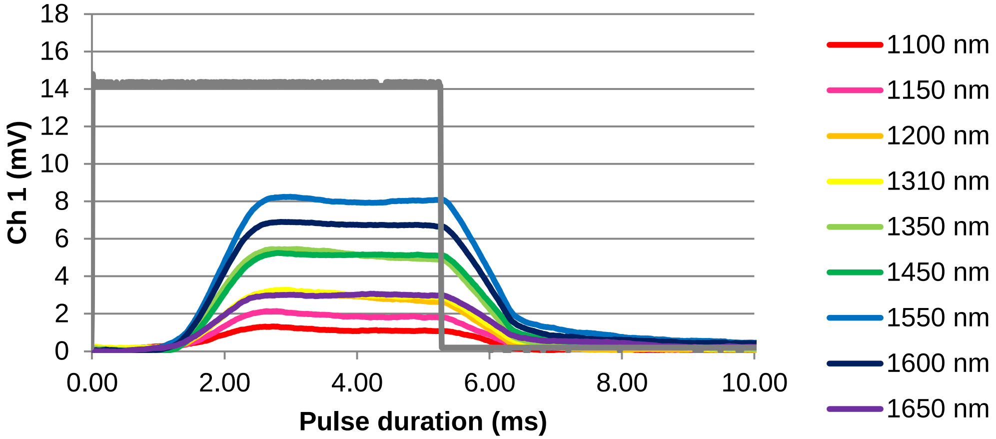

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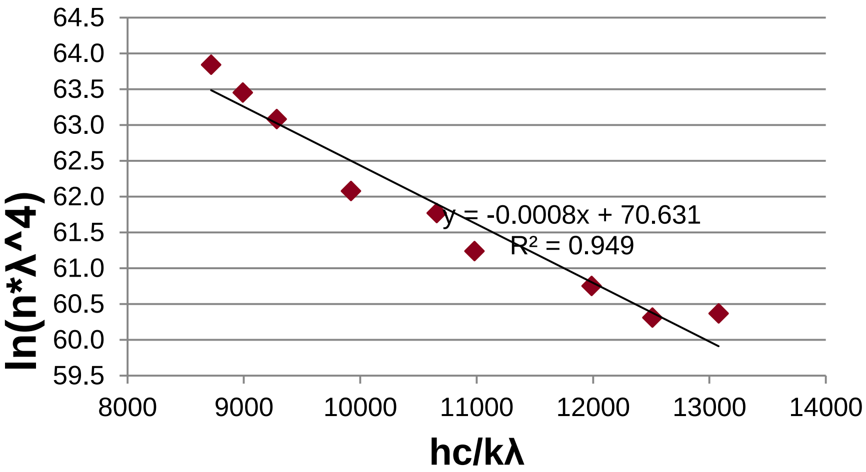
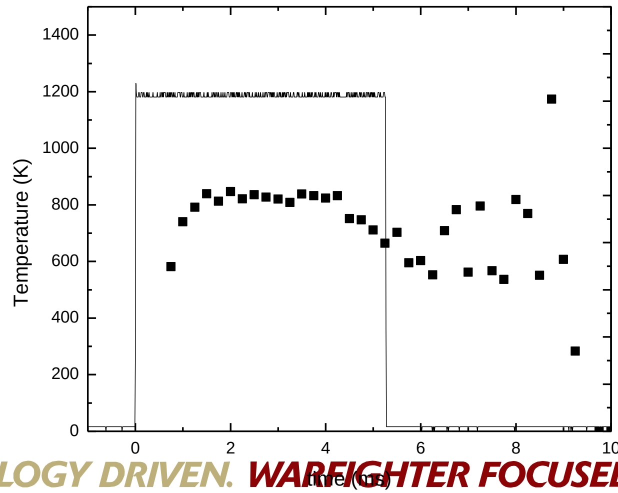
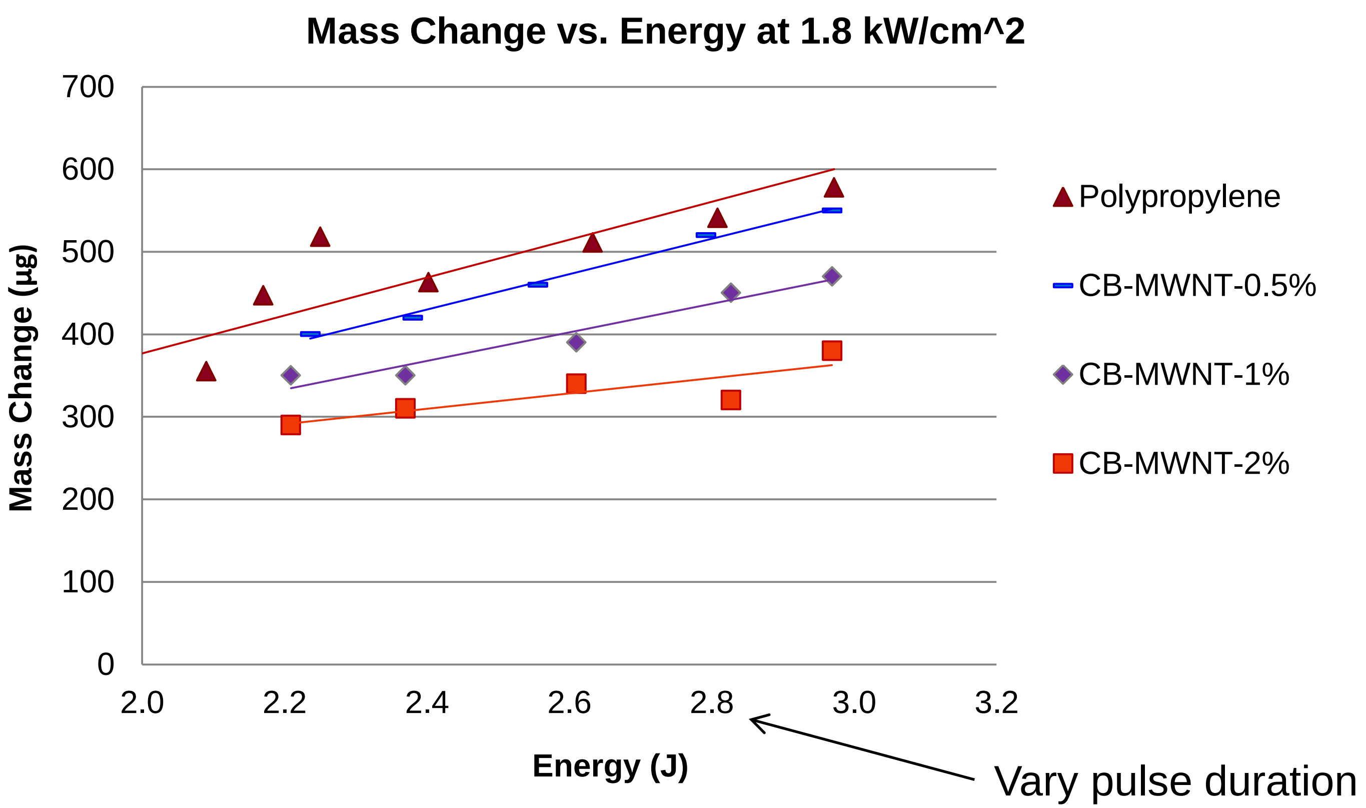


3. Calculate temperature

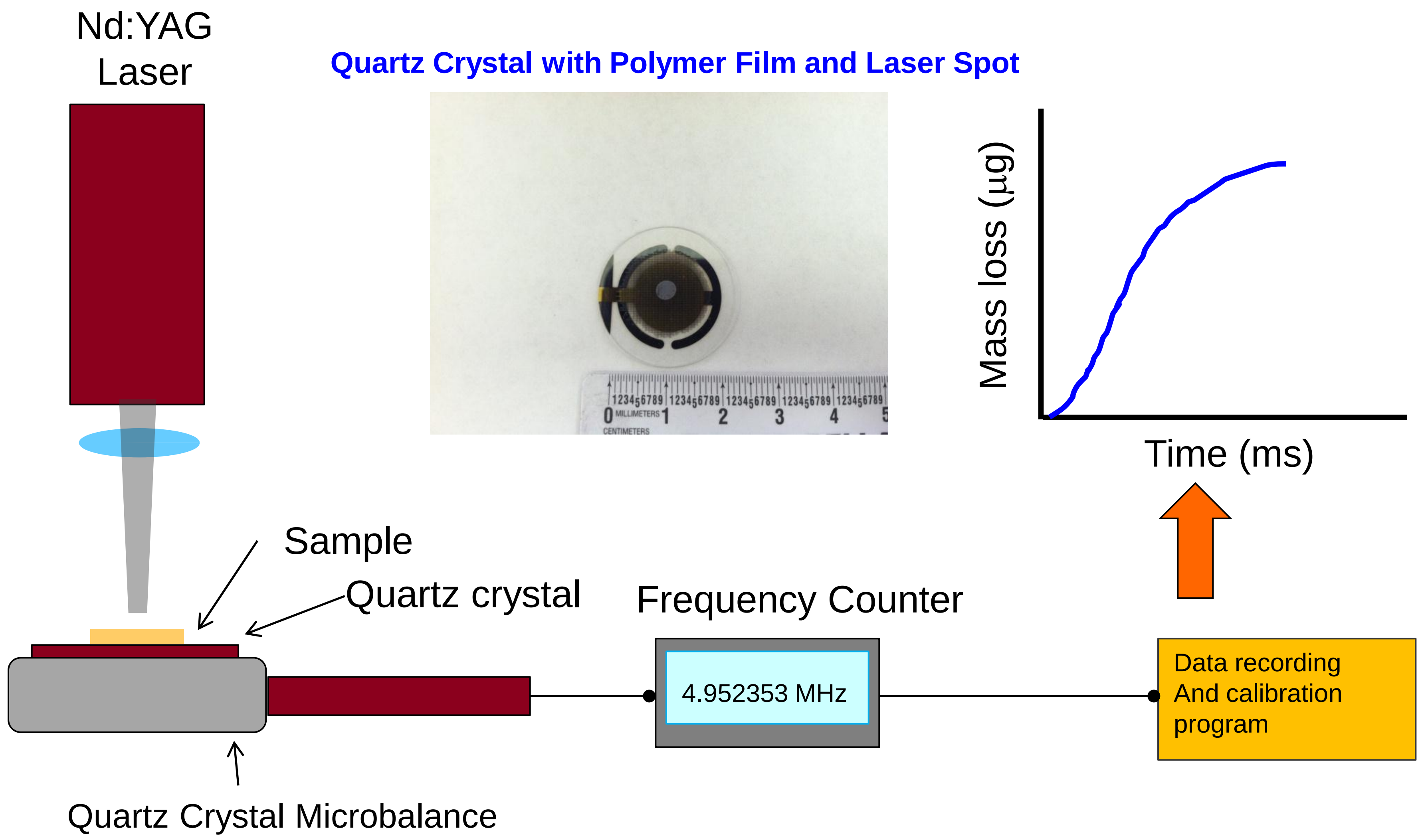


Mass change



- Nano-Clay and Nanotubes decrease mass loss during LPH

Real-time mass measurement



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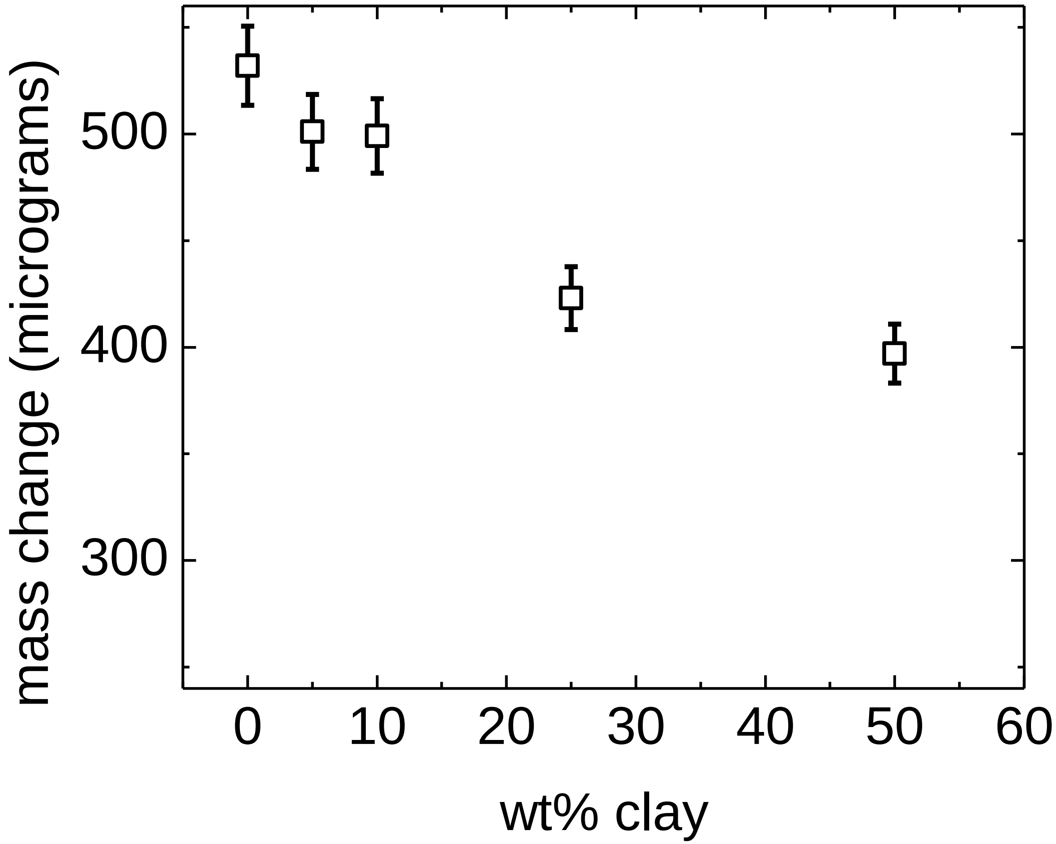
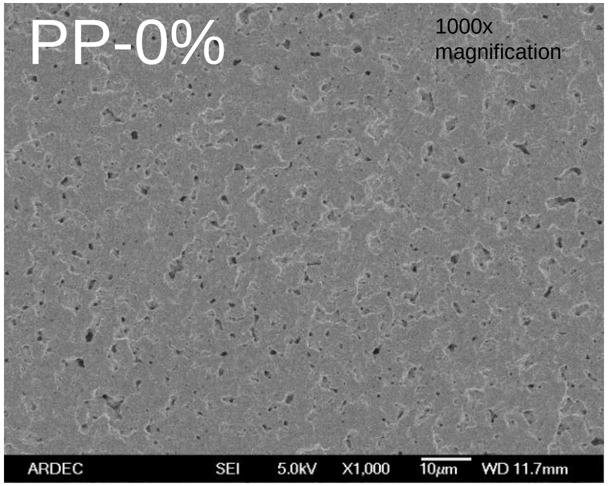
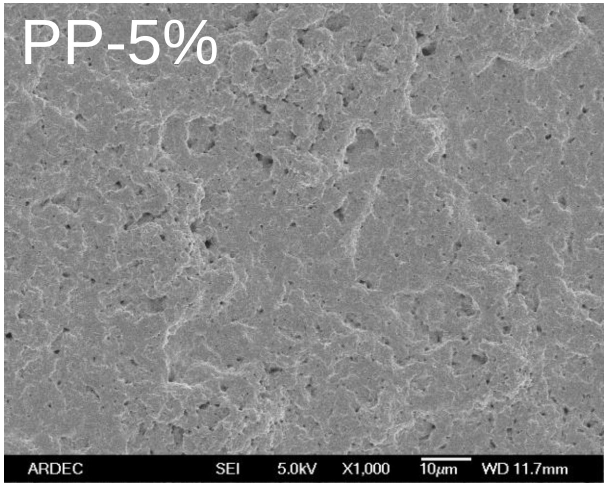
Mass change vs. clay content

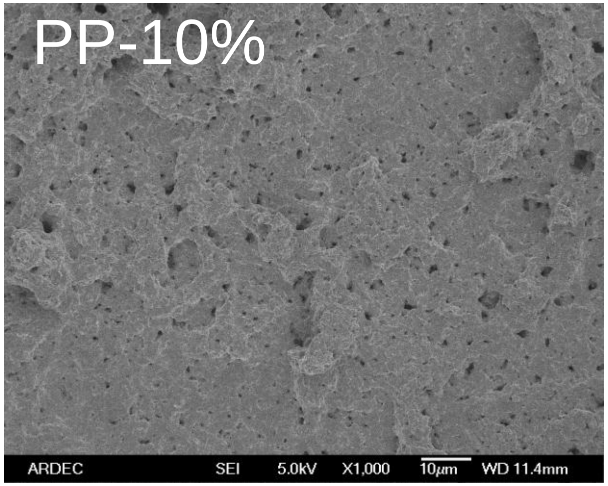


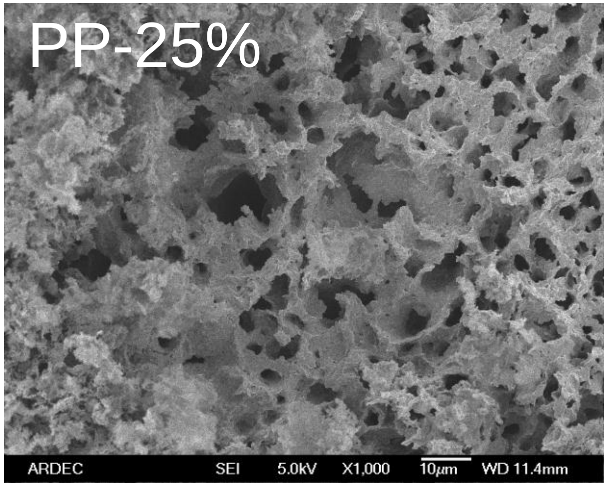
The mass change after a 10 ms shot is reduced as clay content increases

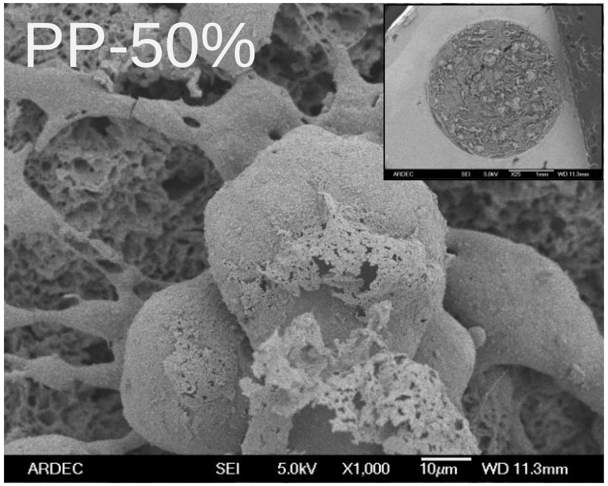
FE-SEM

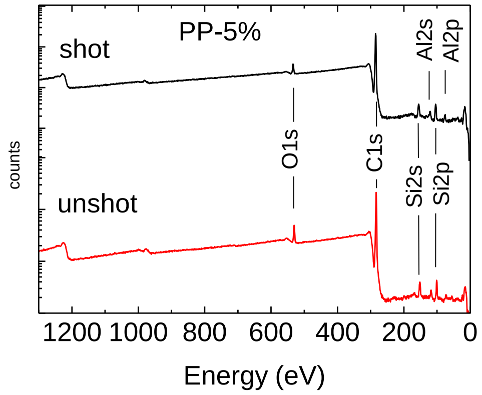








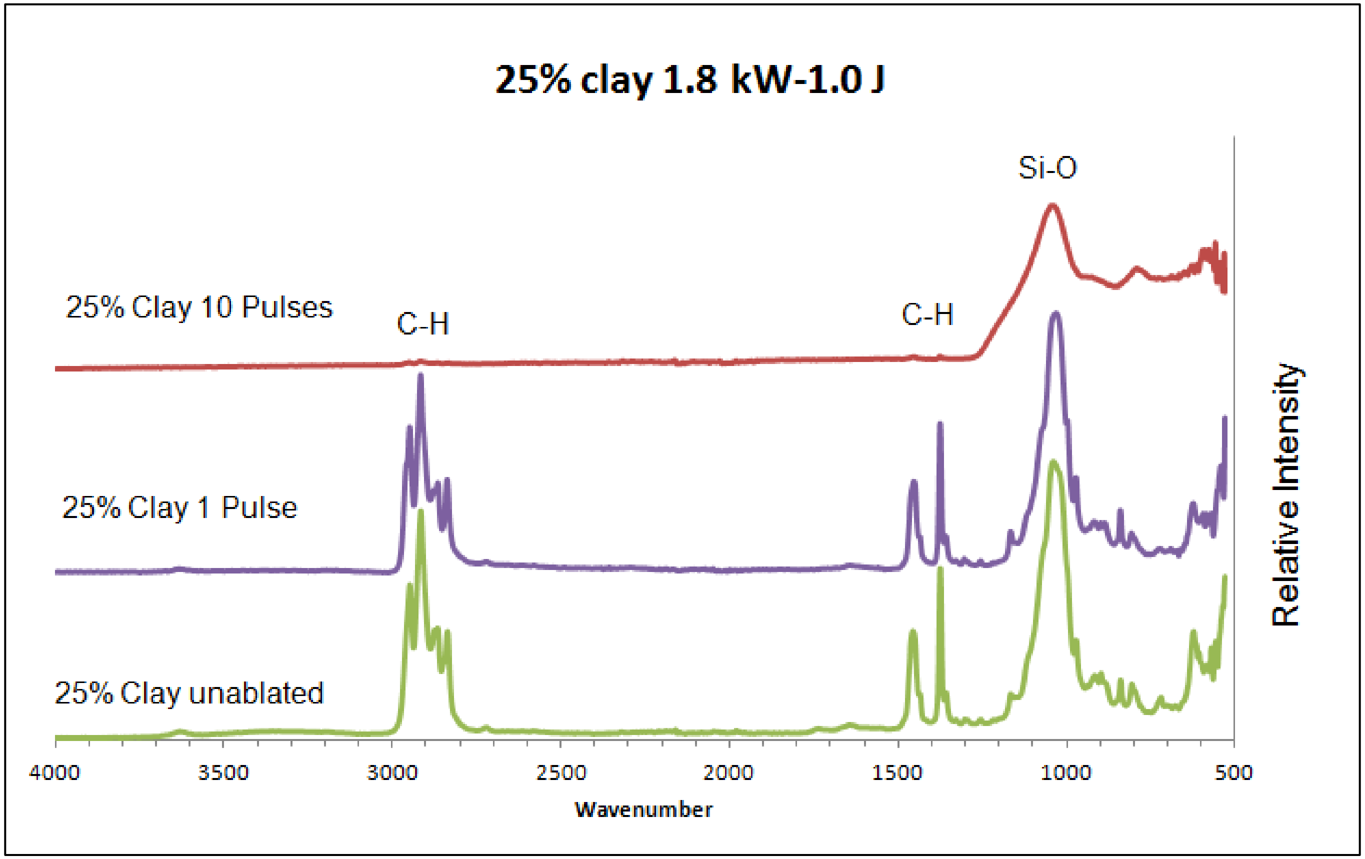




Smooth surface: lower threshold fluence, higher ablation rate and increased gaseous decomposition products seen in polymer ablation *Lippert, 2003, Chem. Rev.

Chemical changes

- We are looking at chemical changes before and after LPH
- TGA-Mass Spectrometry (LPH-MS goal)



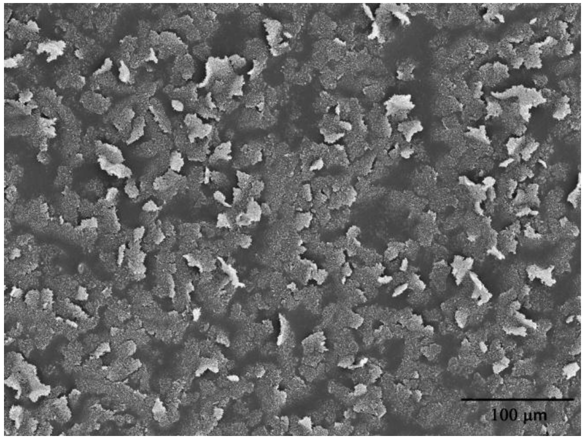
FTIR of clay nanocomposites

Polymer ablated (loss of C-H bonds)

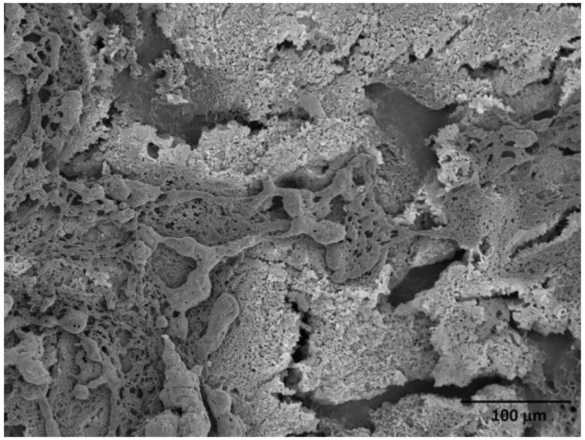
↓

Clay/Oxides remain on surface

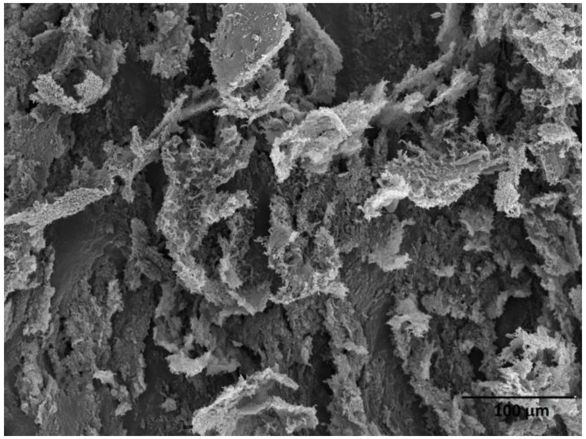
Multi-Pulse Behavior



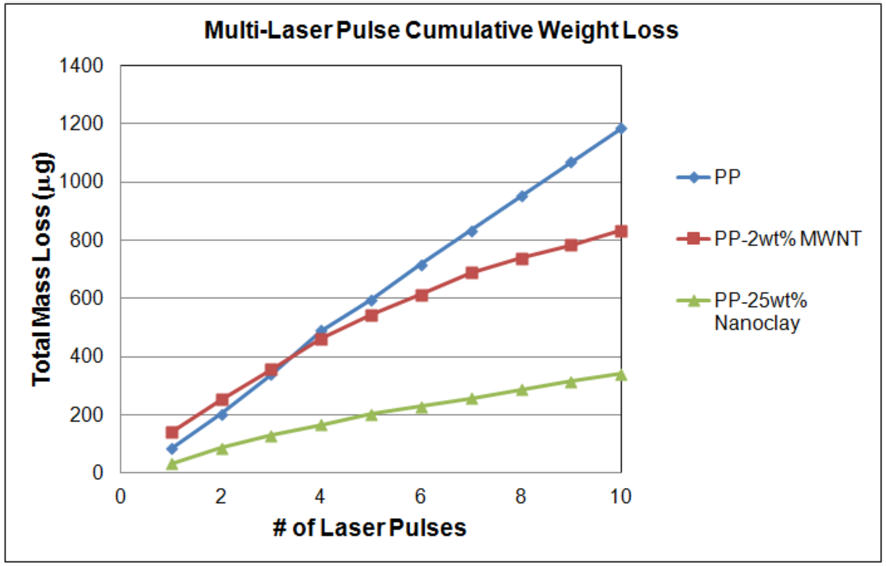
PP



PP-25wt% nanoclay



PP-2wt%MWNT



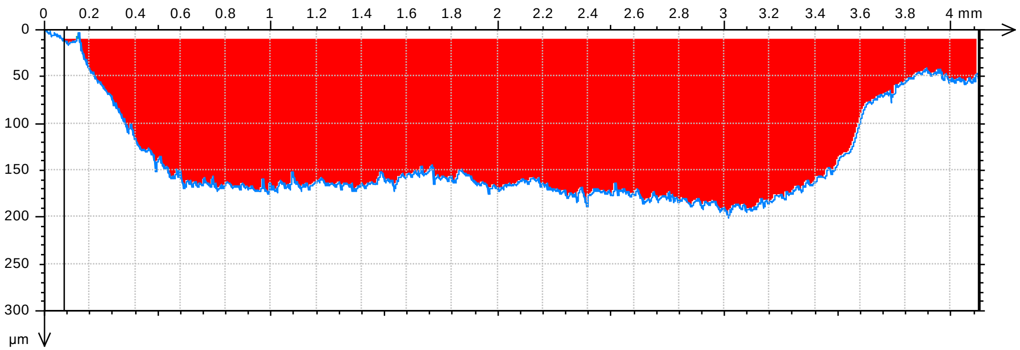
$X=(2Dt)^{0.5}$

 # α t

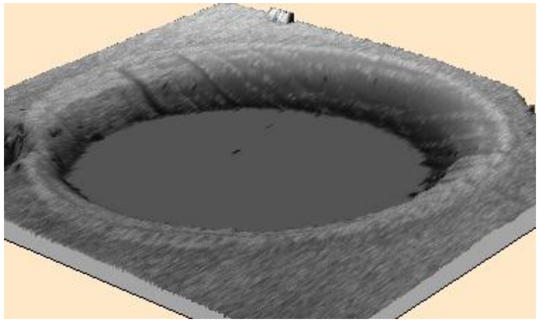
Becomes a diffusion limited Problem.

heat ↓ **mass** ↑

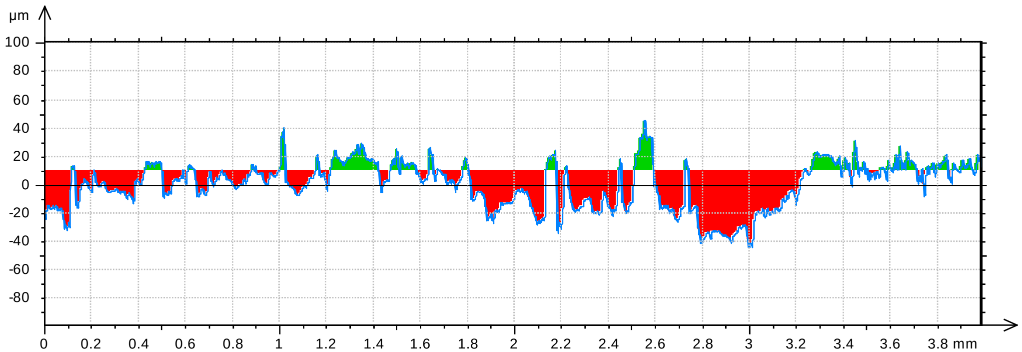
Multi-Pulse Behavior



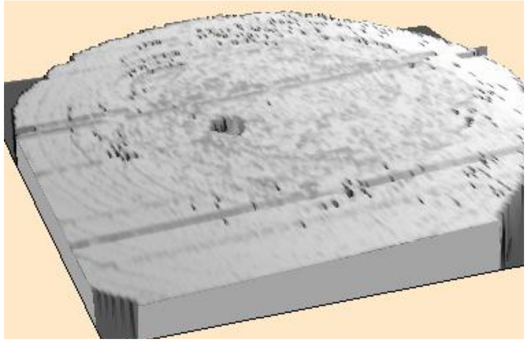
Maximum depth : 191 µm Area of the hole : 0.539 mm2
Maximum height : 7.48 µm Area outside : 59 µm2



PP



Maximum depth : 53.9 µm Area of the hole : 48758 µm2
Maximum height : 35.5 µm Area outside : 9557 µm2



25% clay

Summary

- Research the behavior of polymer nanocomposites during LPH
- Temperatures exceed melting point and degradation temp of base polymer
- Nanoclay and Nanotubes provide degradation resistance
- Novel TGA-LPH technique being developed

Acknowledgements

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  - Lawrence La Beaud
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