# Pulsed Laser Deposition with the Thomas Jefferson National Accelerator Facility Free Electron Laser: Benefits of Sub-Picosecond Pulses with High Repetition Rate

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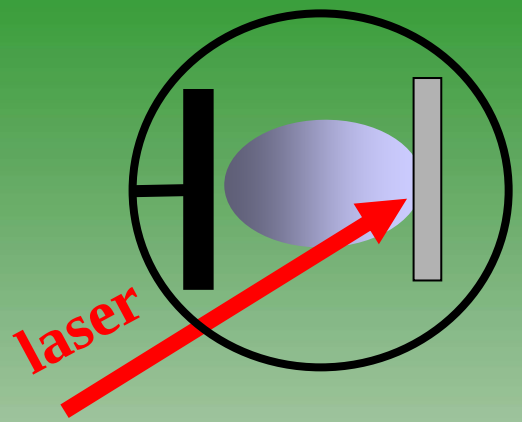
# Summary

The TJNAF-FEL presents unique opportunities in PLD with sub-picosecond pulses, high average power, high repetition rate and tunability.

- Plumes dominated by blackbody radiation
- Produces good films with high deposition rates

# Why pulsed laser ablation and deposition with the FEL?



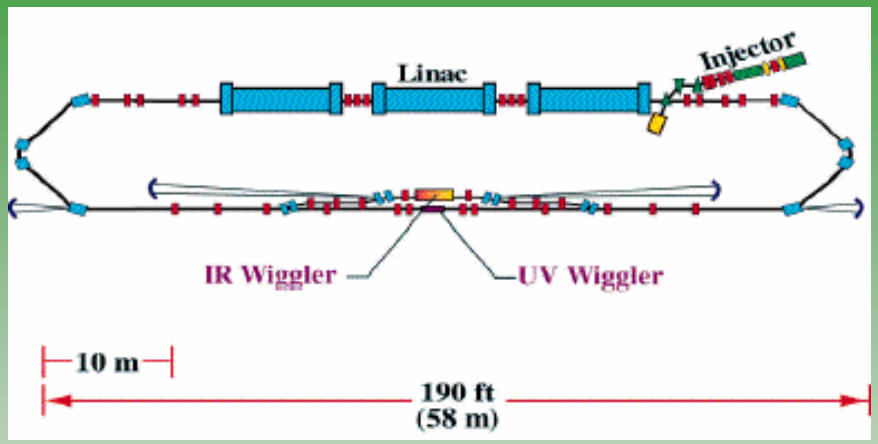

**Advantages of PLD:**

- **FLEXIBLE**
- **GREATER CONTROL OVER ENVIRONMENT**
- **COMPLEX ALLOYING (High Tc superconductors)**
- **EPITAXY AT LOW TEMPERATURE**

**Currently, PLD is limited due to lack of understanding of fundamental processes of laser-target and laser-plasma interactions. Laser sources have been limited.**

# TJNAF- FEL

## Unique *combination of parameters*



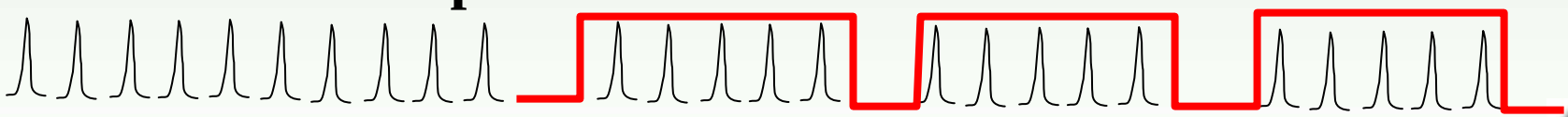

**ULTRAFAST (650 fs)**

**HIGH POWER (>2 kW, 100 μJ/pulse)**

**TUNABLE (1-6 μm, THz and UV upgrade)**

**HIGH REPETITION RATE (18, 34, 74 MHz)**

**CW or Pulsed Operation**



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# Why PLD with the FEL?

## Benefits:

- **ULTRAFAST**: Lower ablation threshold, less target damage, eliminates particulate problem

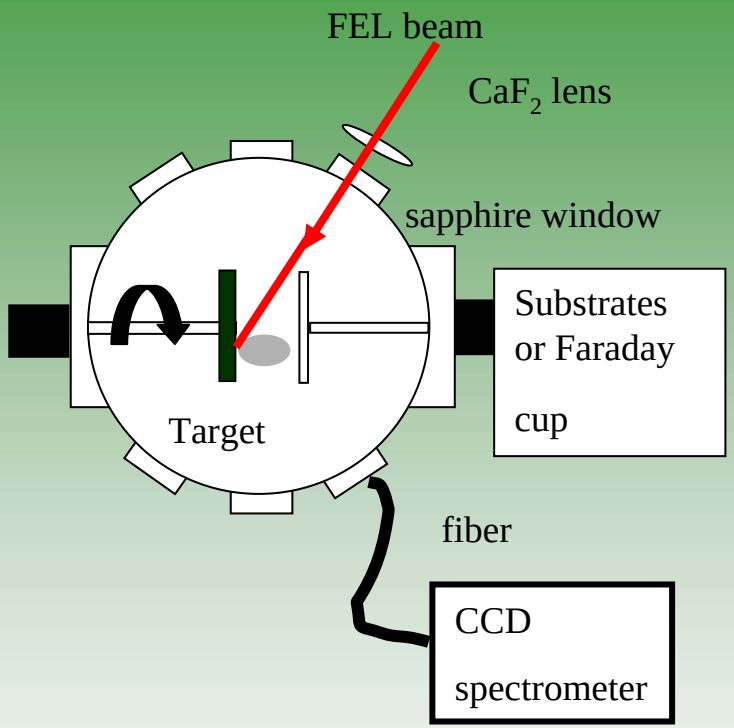
  Gamaly *et al*., Physics of Plasmas, **9** 949 (2002)
- **HIGH REPETITION RATE**: High deposition rate

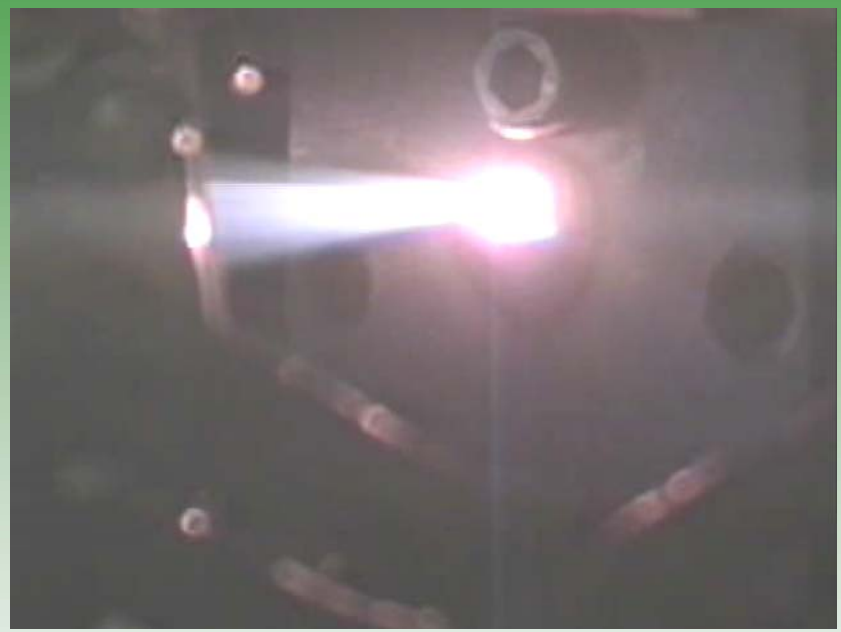
  Gamaly *et al*., J. Appl. Phys., **85** 4213 (1999)
- **TUNABLE**: Enhanced ablation/deposition with resonant absorption

  Park and Haglund, Appl. Phys. A, **64** 431 (1997)

  D. M. Bubb *et al*., Appl. Phys. Lett, **79** 2847 (2002)

# FEL-PLD experimental setup



8” Chamber, 1 x $10^{-6}$ Torr
FEL at 3.1 μm

FEL plasma plume
Nb target, cw beam, ~ 0.6 J/cm$^2$

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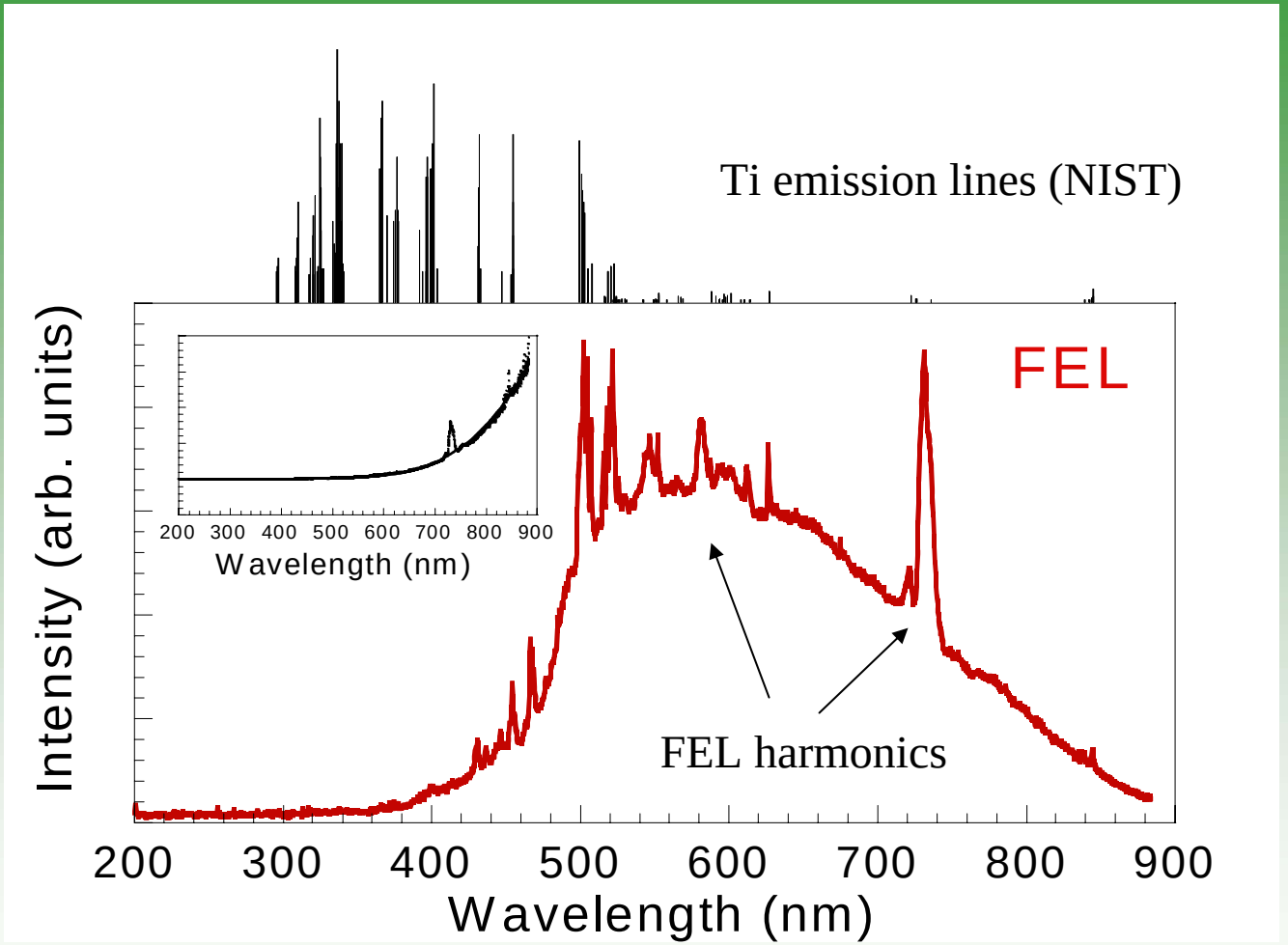
# Optical spectra shows significant blackbody emission:




Titanium target

Red curve uncorrected response

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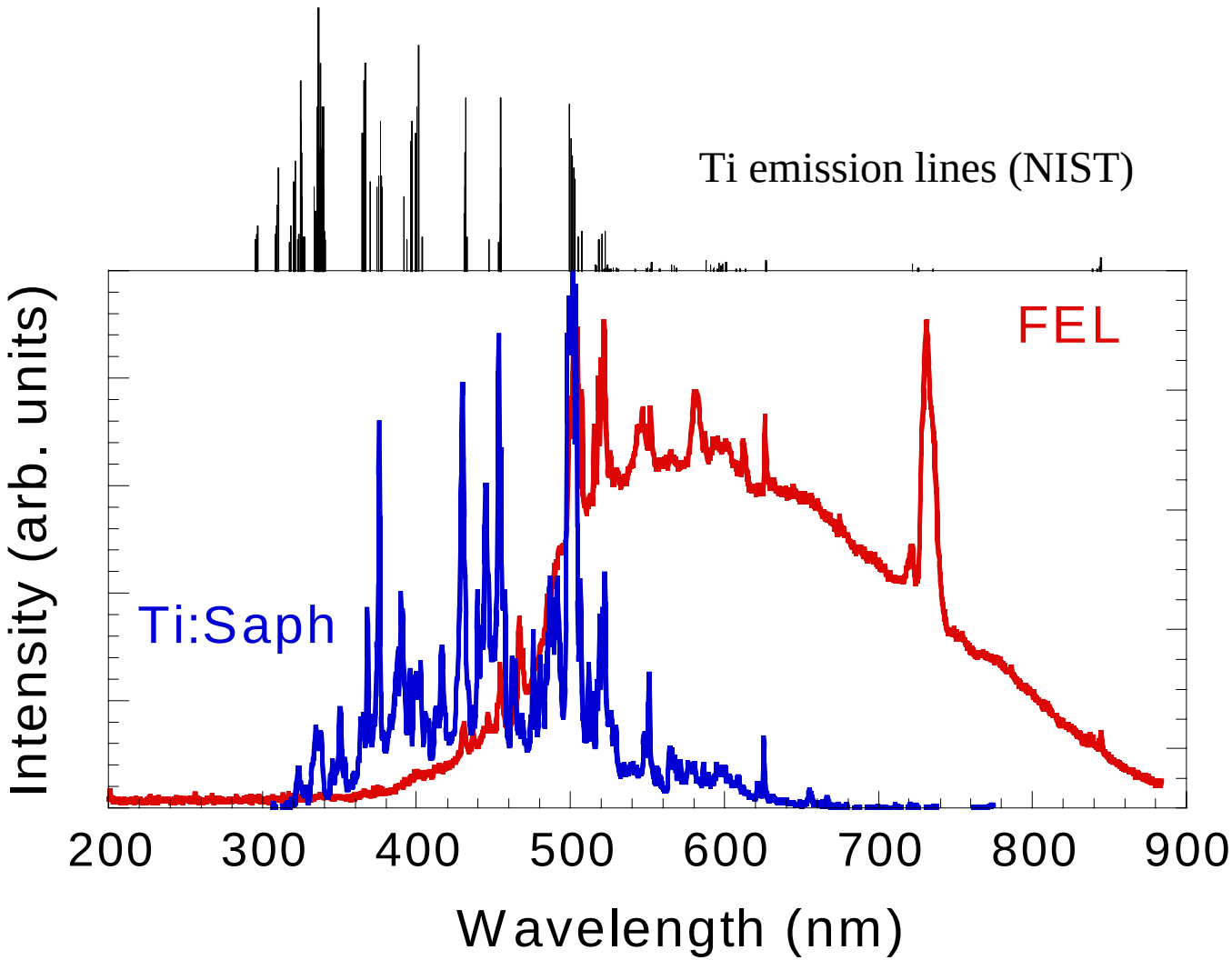
# Compared with amplified Ti:Saph ablation (1 mJ/pulse, 1 kHz):



## Blackbody radiation with FEL ablation:

## Dense Plasma?

G. Mehlman *et al*., J. Appl. Phys., **74** 53 (1993)

## Heating of nanoparticles?

D. B. Geohegan *et al*., Appl. Phys. Lett., **62** 1463 (1993)



# Thin Film Quality (Magnetic Materials)

**Benefit of sub-picosecond pulses and high repetition rate: high quality films with high deposition rates**

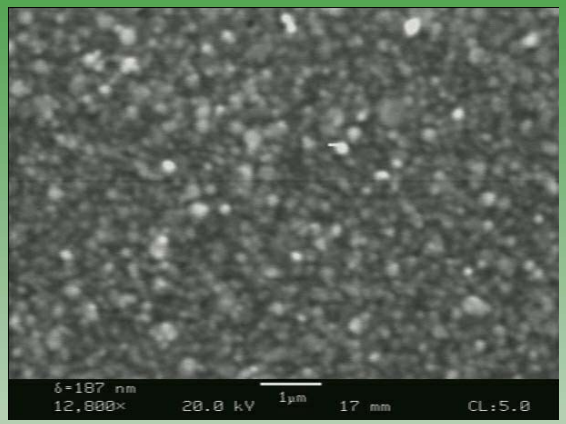
**Demonstrated in comparison to amplified Ti:Sapphire system (150 fs, 1 mJ/pulse, 1 kHz)**

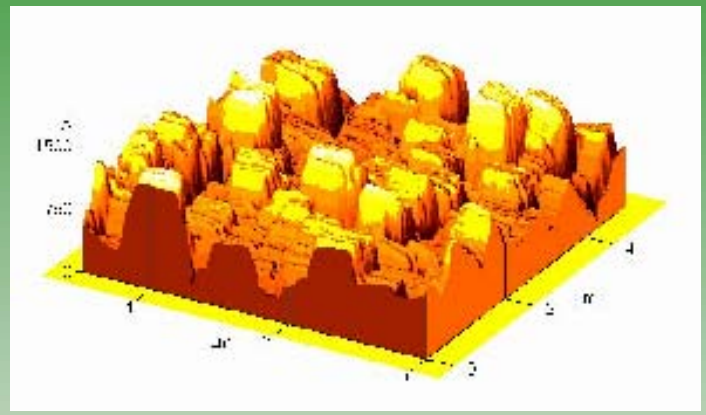


# Amplified Ti:Sapphire versus FEL (NiFe)

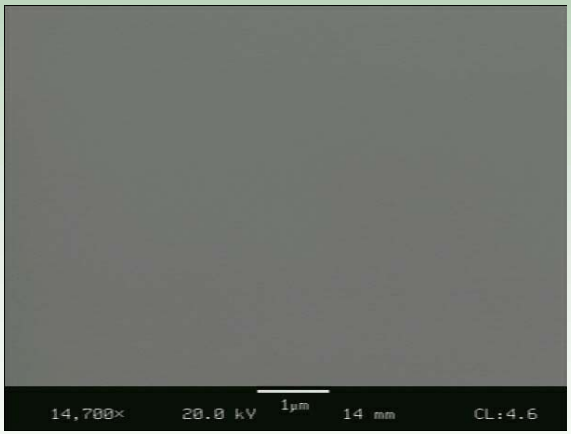
Exploring dependence on pulse power and repetition rate

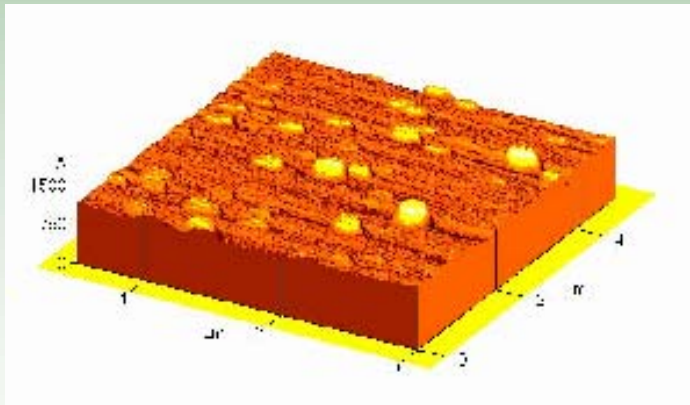
Amplified TS
0.7 mJ/1 kHz



FEL
5 μJ/37.4 MHz



SEM

AFM

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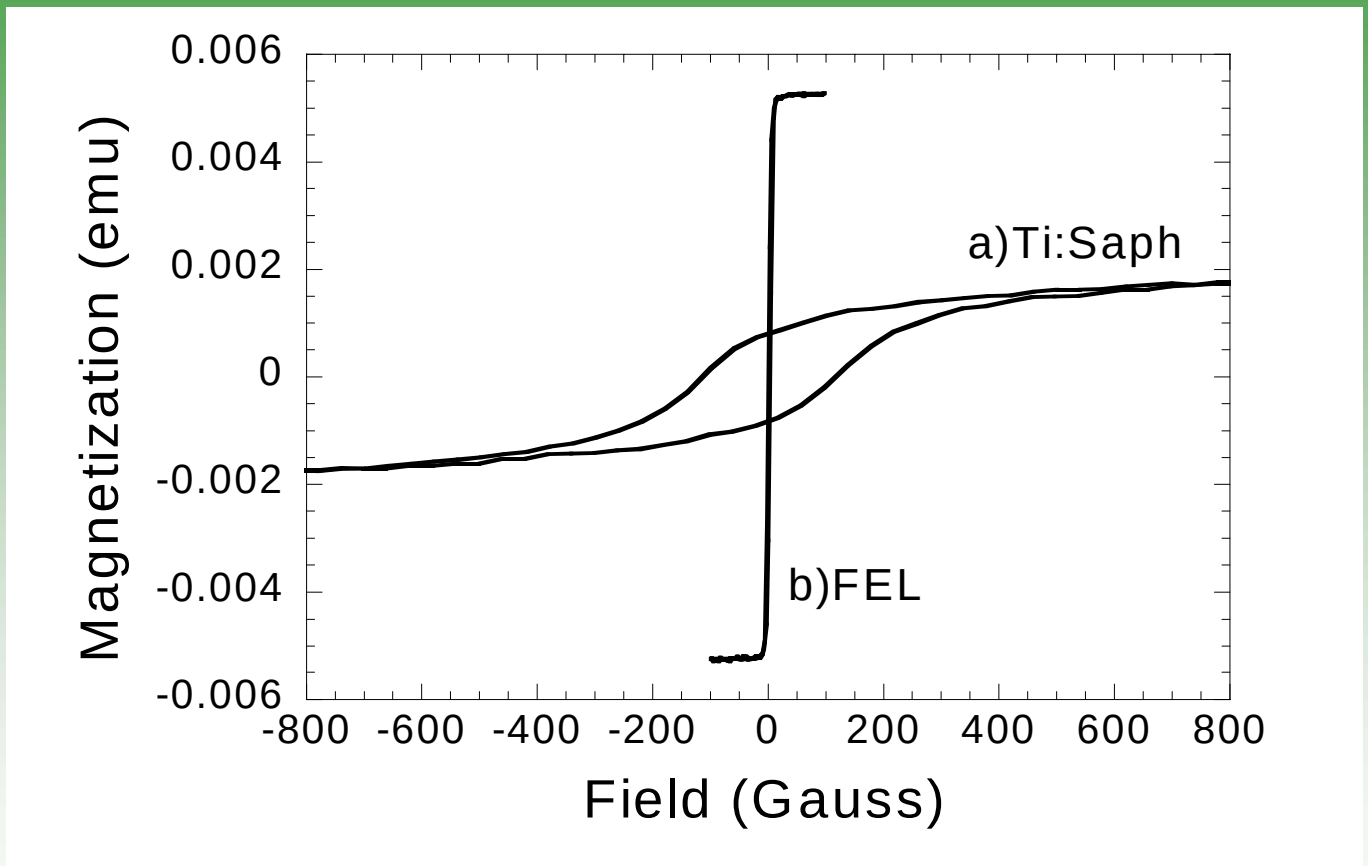
# Amplified Ti:Sapphire versus FEL (NiFe)

Large effect on magnetic properties




Crystallized Fe? Crystalline orientation? Roughness?

# Amplified Ti:Sapphire versus FEL (NiFe)

## Deposition Rates

**Amp. Ti:Saph**
1 mJ/pulse, 1 kHz
1 Å/s
$1 \times 10^{-3}$ Å /pulse

**FEL**
5 μJ/pulse, 37.4 MHz
17 Å/s
$5 \times 10^{-7}$ Å /pulse

Possibility of much higher rates with FEL:

200 Å/s for Nb  M. Shinn, Proc. SPIE (2000)



# Conclusions

- The TJNAF-FEL gives a unique combination of laser parameters
- Interesting opportunities to explore laser-target and laser-plasma interactions
- FEL-PLD gives high quality films with very high deposition rates