

Introduction to Ultrafast Laser

Lecture 1: Basic Facts & Outline

Wenjie Chen

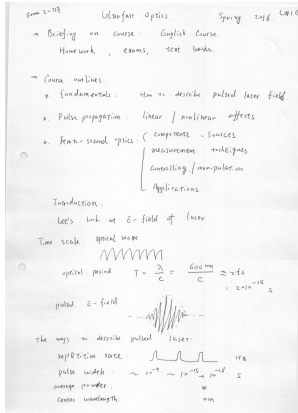
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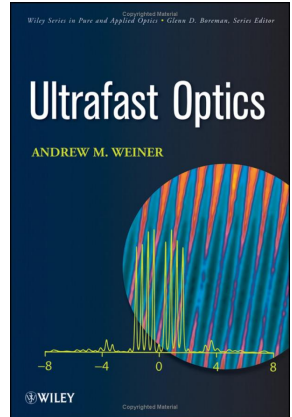
April 30, 2019

Before we start ...

- References;
- All lecture slides are **available online**;
- You are encouraged to stop me and ask any questions related to the lecture.



Prof. Kevin Shi, Spring 2019



by Andrew M. Weiner

Overview

1 Basic Facts about Ultrafast Laser

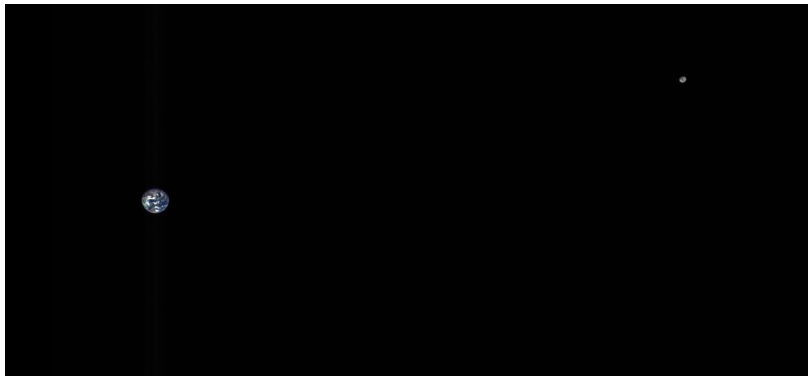
- Time Scale
- Shape
- Important Parameters
- Remark

2 Outline for Following Lectures

Time Scale

How fast is ultrafast?

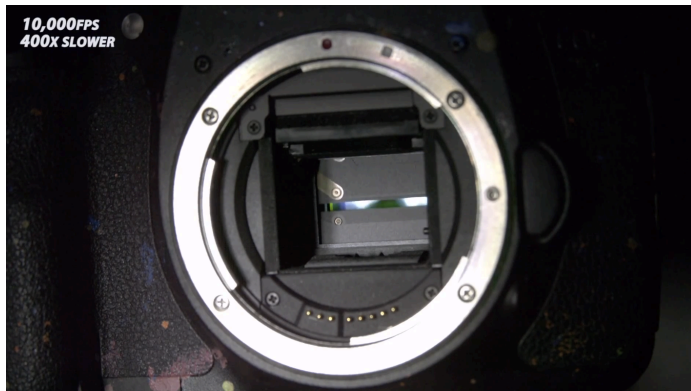
second (1 s): Light travels 299,792,458 m ($\approx 3/4$ moon-earth distance) in vacuum.



Time Scale

How fast is ultrafast?

millisecond ($1\text{ ms} = 10^{-3}\text{ s}$): The fastest standard shutter speed for a normal camera.



Time Scale

How fast is ultrafast?

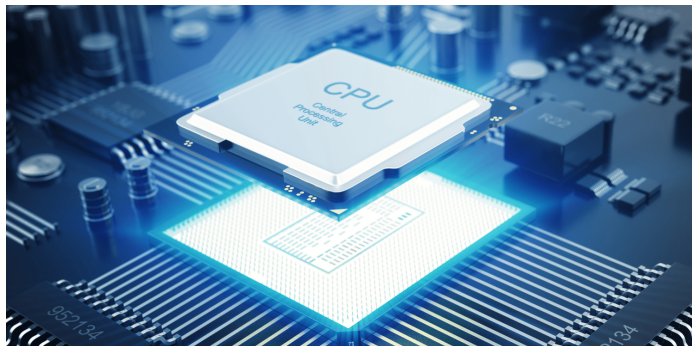
microsecond ($1\ \mu\text{s} = 10^{-6}\ \text{s}$): Time duration for a high speed camera flash (to freeze the motion). J-20 can only travel about 1 mm at its maximum speed (2.8 Mach).



Time Scale

How fast is ultrafast?

nanosecond ($1 \text{ ns} = 10^{-9} \text{ s}$): Modern CPUs' common clock rate (GHz).



Time Scale

How fast is ultrafast?

picosecond ($1 \text{ ps} = 10^{-12} \text{ s}$): Light travels about 0.3 mm in vacuum. Typical time scale for many dynamical processes (e.g. chemical reactions, molecular rotation).

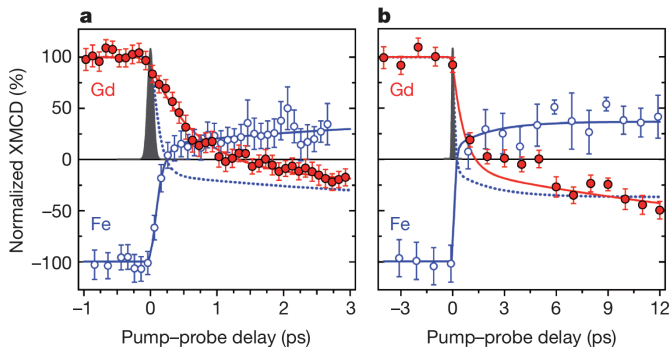


Figure: Spin reversal in ferrimagnetic alloy GdFeCo. I. Radu *et al.*, *Nature* **472**, 205–208 (2011).

Time Scale

How fast is ultrafast?

femtosecond ($1 \text{ fs} = 10^{-15} \text{ s}$): The time period of light with $\lambda = 632.8 \text{ nm}$ is about 2 fs. Typical time scale for ultrafast laser pulses.

The Nobel Prize in Chemistry 1999 was awarded to Ahmed H. Zewail “*for his studies of the transition states of chemical reactions using femtosecond spectroscopy.*”



Figure: Ahmed H. Zewail

Time Scale

How fast is ultrafast?

attosecond ($1 \text{ as} = 10^{-18} \text{ s}$): Typical time scale for dynamical processes inside atoms (e.g. tunneling in ionization).

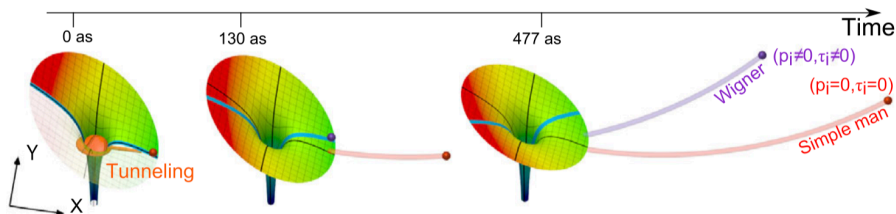


Figure: Ionization process in atoms. Nicolas Camus *et al.*, *Phys. Rev. Lett.* **119**, 023201 (2017).

Overview

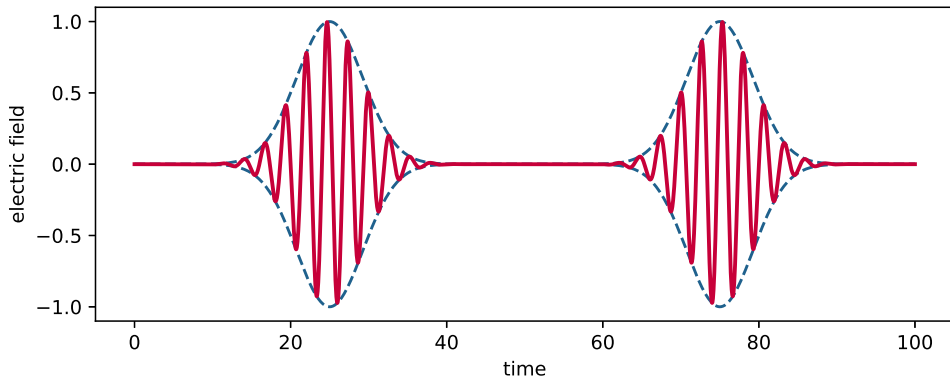
1 Basic Facts about Ultrafast Laser

- Time Scale
- Shape
- Important Parameters
- Remark

2 Outline for Following Lectures

Shape of the Ultrafast Laser Pulses

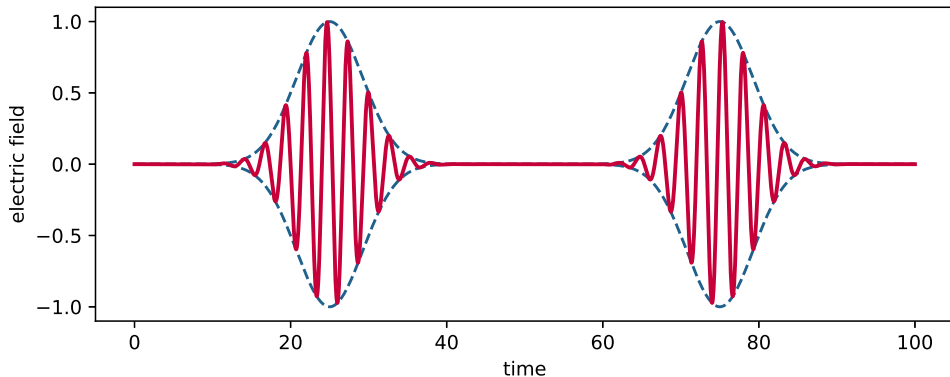
Envelope and carrier.



Totally wrong in quantity!

Shape of the Ultrafast Laser Pulses

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Totally wrong in quantity!

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Important Parameters

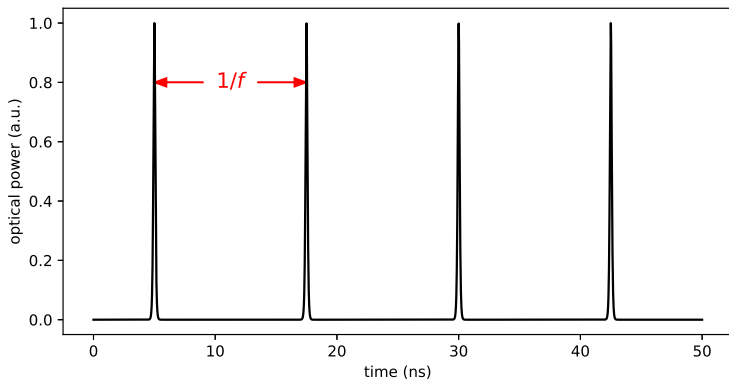
How to describe pulsed laser?

- **repetition rate**
- **pulse width**
- **average power**
- **center wavelength**

Important Parameters

Repetition rate: the number of pulses in one second. [kHz to MHz]

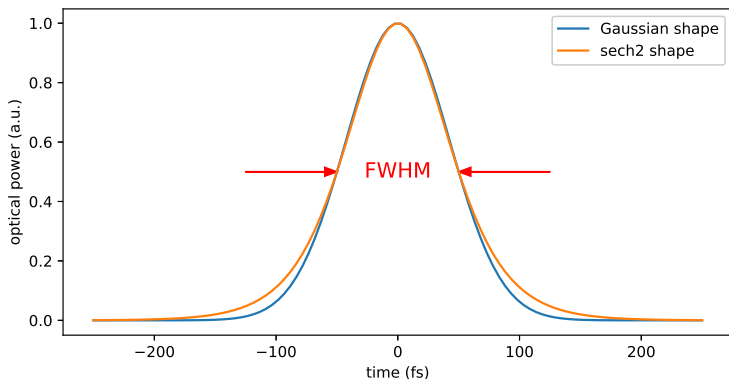
- Mai Tai ® Ultrafast Ti:Sapphire laser: $80 \text{ MHz} \pm 1 \text{ MHz}$.
- Period time: 12.5 ns.



Important Parameters

Pulse width (a.k.a pulse duration or pulse length): FWHM (*usually*). [fs]

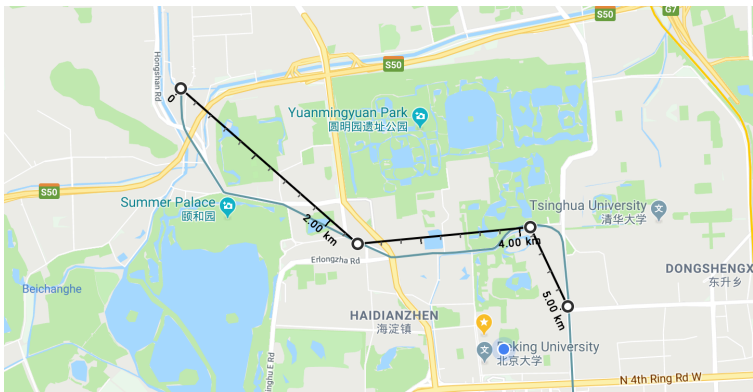
- Mai Tai ® Ultrafast Ti:Sapphire laser HP: < 100 fs.
- **Gaussian:** $I(t) = I_0 \exp[-4 \ln(2) t^2 / \tau^2]$. **sech2:** $I(t) = I_0 \operatorname{sech}^2(-t/\tau) \{1.665 \tau\}$.



Important Parameters

Pulse width (a.k.a pulse duration or pulse length): FWHM (*usually*). [fs]

- duty cycle = pulse width / $T = 8 \times 10^{-6}$.
- 4 minutes in 1 year, ping pong ball in 5 km!



Important Parameters

Average power. [W]

- Mai Tai HP at 800 nm: > 2.5 W.

- Pulse energy:

$$E_p = 2.5 \text{ W} / 80 \text{ MHz} = 0.3125 \text{ } \mu\text{J}$$

- Peak power (Gaussian):

$$P_p = 0.94 \times E_p / 100 \text{ fs} = 2.94 \times 10^6 \text{ W}$$

- Peak intensity (focus on a 10 μm diameter spot)

$$I = P_p / A = 3.74 \times 10^{12} \text{ W/cm}^2$$

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Important Parameters

Average power. [W]

- Electric field:

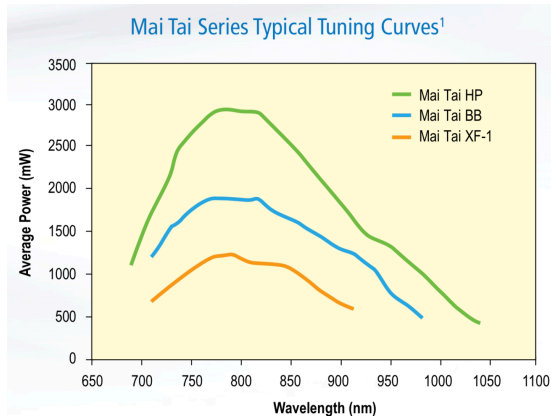
$$I = \frac{1}{2} c \epsilon_0 E^2 \Rightarrow E = 5.3 \times 10^9 \text{ V/m}$$

- An extremely intense field, about 5.2 Å away from an electron (recall: $a_0 = 0.53 \text{ Å}$)!

Important Parameters

Center wavelength. [nm]

- Mai Tai HP: tunable from 690 nm to 1040 nm.



Important Parameters

How to describe pulsed laser?

Mai Tai ® Ultrafast Ti:Sapphire laser HP

- **repetition rate:** 80 MHz (maybe too large).
- **pulse width:** 100 fs (two shapes).
- **average power:** 2.5 W (peak power $\sim 3 \times 10^6$ W).
- **center wavelength:** tunable from 690 nm to 1040 nm.

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Remark

Frequency spectrum.

- Continuous Wave (CW) laser: infinity long laser \rightarrow narrow bandwidth
- Ultrafast laser: short laser pulses \rightarrow wide bandwidth with “teeth” (frequency comb).

Remark

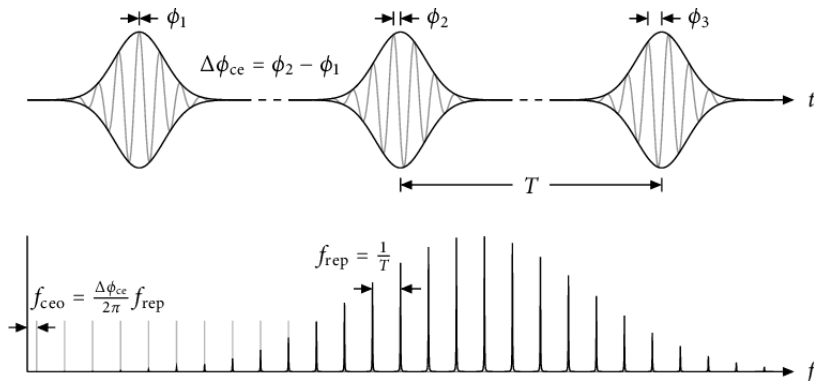
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Outline for Following Lectures

Topic	# of lectures
mathematical description	1-2
propagating and dispersion	1-2
nonlinear and chirping effect	2
optical components	2
methods to generate ultrafast laser	?
paper reading	?
...	...

The End