Ultrafast Optics

Adv. Optics - PHYS-545

Presented by

Buddika Abeyweera

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Outline...

- Introduction to Ultrafast Optics
- Pulse Characteristics
- Generation of Ultrafast Laser pulses
- Pulse Detection
- Ultrafast Optics: Applications
- Summary & References
Introduction to Ultrafast Optics

• 1s Light pulse => Spatial extent = 186K miles.
• Light pulses of widths in the nano-pico seconds...(ns-ps) ($10^{-9} – 10^{-12}$ s).
• Fs pulse corresponds to NIR-VISIBLE 750-400nm.
• Attosecond corresponds to Extreme UV & X-ray regions.
Basics of Light Pulses

• A monochromatic plane wave is given by

\[ E_y = \text{Re}\{E_0 \exp(i\omega_0 t)\} \]

Which is a cosine function propagating in time \( t \).
Constructing a PULSE

• Multiplying a plane wave with a bell-shaped function
• For simplicity, bell-shaped function
  => Gaussian Function!
  \[ E_y = \text{Re}\{E_o \exp(-\tau t^2 + i\omega_0 t)\} \]
Analyzing a Light pulse

- The Fourier transform of plane wave is a Dirac Distribution function of $\delta(\omega_o)$.

$$\delta(\omega_o) = \lim_{t \to \infty} \int_{-\infty}^{\infty} e^{i(\omega - \omega_o)t} \, dt$$

- Width of the cosine function grows larger
  - $\Rightarrow$ Dirac Function ($\delta(\omega_o)$) moves toward zero width.
Pulse Characteristics

(1) Temporal & Spectral width:
- Temporal width of a pulse is the width of Intensity defined as $I(t)$ denoted by $\tau_{\text{FWHM}}$.
- Spectral width of a pulse is the width of Spectral intensity defined as $S(\nu)$ denoted by $\Delta \nu$.

Chirped Pulses:

Pulse of which the instantaneous frequency varies with time.

Instantaneous frequency:

$$v_i = v_o + \frac{1}{2\pi} \frac{d\varphi}{dt}$$
Pulse Characteristic

- (2) Gaussian & Chirped Gaussian:
  Gaussian pulse has a magnitude & intensity given by

\[ A(t) = A_0 e^{-\frac{t^2}{\tau^2}} \]
\[ I = I_0 e^{-\frac{2t^2}{\tau^2}} \]

Chirped Gaussian can be either ‘positive’ or ‘negative’!
Pulse Characteristics

(3) Spatial Characteristics:

Pulse travels in non-dispersive, linear, homogeneous media can be categorized into Plane pulse, Spherical pulse or Gaussian pulse.

- Plane
- Spherical
- Gaussian
Pulse Generation
Mode locking

- Short pulse generating lasers produce many modes with frequencies separated by $\nu_F = c/2d$
- Externally coupling these modes and lock their phases together – ‘Multi-mode locking’
- These modes are components of a Fourier series with a time period of $1/\nu_F$
Active Mode-Locking Technique

- First & simplest technique

- Modulator acts as a periodic shutter which opens & closes once per round trip
Pulse Detection

• Issues:
  • Slow Detectors
  • Alteration of the pulse characteristics by the equipment before it’s been measured.

• Measurement of Intensity & Spectral Intensity:
• Measurement of Spectrogram:
• Measurement of Amplitude & Phase:
Pulse Detection - FROG Method
Frequency Resolved Optical Gating

PG-FROG
Ultrafast/Ultrashort Pulse: Applications-Ultrafast Spectroscopy

- Pump-probe approach for time-resolved spectroscopy
- Probe pulse creates Raman scattering at frequencies...
  Where $\omega_{vi}$ is the frequency of the Raman mode.

$$\omega_p \pm \sum_i \omega_{vi}$$
Summary

• Pulse of a light is described as an optical field with finite time duration of which the pulse characteristics can be obtained.

• Ultrafast light pulse can be generated by Mode-locking technique.

• FROG technique can be used to identify information about phase of the pulse in addition to the amplitude.

• Ultrafast pulses reveal more information of the interaction between the light and matter using ultrafast spectroscopic techniques.
References


Thank You...