Ultrafast Pulse Generation using a Ti:sapphire Laser
or
FROGS, SPIDERS, and flying pancakes

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Motivation:
What is “Ultrafast” and why should we bother?
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Generation of Ultrashort Pulses:
Fast, Faster, ... The Ti:sapphire Laser
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Measurement Techniques:
Why physicists do have a sense of humor.
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Measurement Techniques: Why physicists do have a sense of humor.

Experimental Results: Spectral and Pulsewidth Measurements of two different Ti:sapphire Lasers
Outline

• Motivation:
  What is “Ultrafast” and why should we bother?

• Generation of Ultrashort Pulses:
  Fast, Faster, … The Ti:sapphire Laser

• Measurement Techniques:
  Why physicists do have a sense of humor.

• Experimental Results:
  Spectral and Pulsewidth Measurements of two different Ti:sapphire Lasers

• Conclusion:
  Where do we go from here?
What is “Ultrafast”? 

- **Today:** Sub-picosecond pulses can easily be generated.
- **Example:** 15 fs pulse at 800 nm $\Rightarrow$ 4.5 $\mu$m thin disk of light, six wavelength long
- **Sub 5 fs pulses have been generated**
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  - useful for medical applications, e.g. OCT
  - “Freeze” fast processes in time
  useful in Chemistry and Biology
Generation of Ultrashort Pulses

- Q-switching? Not really.
- active and passive modelocking
  - additive pulse modelocking (APM)
  - colliding pulse modelocking (CPM)
  - Kerr-lens modelocking (KLM)
- extra cavity optical pulse compression
- soliton lasers
- suitable laser gain media
  Ti:sapphire, Nd:YLF, Cr:LiSAF, Cr:Forsterite
• Direct Detection: The Streak-Camera
Measurement Techniques

- Direct Detection: The Streak-Camera
- Indirect Detection: Autocorrelators
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TPA vs. SHG Autocorrelators

Major advantages of TPA using a photodiode are:
- very sensitive (\(\sim\) pJ)
- broad spectral response
- easy to implement
- really, really, really cheap (\(\sim\) $8 for GaAsP diode)
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Major disadvantages using SHG crystal

- sub 10 fs pulse requires < 25 \( \mu m \) crystal
- sensitivity decreases with thickness of crystal
- sensitive to angular misalignment
- really, really, really expensive
Real-time and single-shot characterization of femtosecond laser pulses possible

- **SPIDER**
  Spectral Phase Interferometry for Direct Electric-field Reconstruction
Brand New Techniques

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- GRENOUILLE
  GRating-Eliminated No-nonsense Observation of Ultrafast Incident Laser Light E-fields
The signal out of an autocorrelator can be modeled by

\[ G(\tau) = \int_{-\infty}^{\infty} \left\{ \left[ E(t - \tau) + E(t) \right]^2 \right\}^2 dt \]
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For an unchirped Gaussian pulse envelope, we get

\[ G_{\text{int}}(\tau) = \sqrt{\frac{\pi}{a}} + 2\sqrt{\frac{\pi}{a}} \cdot \exp\left(-a\tau^2\right) \]

for the intensity autocorrelation function.
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\[ G(\tau) = \int_{-\infty}^{\infty} \left\{ [E(t - \tau) + E(t)]^2 \right\}^2 \, dt \]

For an unchirped Gaussian pulse envelope, we get

\[ G_{nc}(\tau) = \sqrt{\frac{\pi}{a}} + 2\sqrt{\frac{\pi}{a}} \cdot \exp(-a\tau^2) + \sqrt{\frac{\pi}{a}} \cdot \exp(-a\tau^2) \cdot \cos(2\omega_0\tau) \]

\[ + 4\sqrt{\frac{\pi}{a}} \cdot \exp\left(-\frac{3a\tau^2}{4}\right) \cdot \cos(\omega_0\tau) \]

for the interferometric autocorrelation function.
• Theory: 15 fs Gaussian pulse centered around 800 nm
Autocorrelation:
Theory and Experiment

- **Theory:**
  15 fs Gaussian pulse centered around 800 nm

- **Experiment:**
  Intensity autocorrelation

![Graphs showing theoretical and experimental autocorrelation](image-url)
Autocorrelation: Theory and Experiment

- **Theory:**
  
  15 fs Gaussian pulse centered around 800 nm

- **Experiment:**
  
  Intensity autocorrelation

  Interferometric autocorrelation
Autocorrelation traces don’t tell the whole story…

Spectral Measurements

![Graph](image_url)

- **Experimental Data (KMLabs TS)**
  - Gaussian Fit (TS)
  - FWHM = 40.345 nm
- **Experimental Data (Spectra-Physics Tsunami)**
  - Gaussian Fit (Tsunami)
  - FWHM = 9.075 nm

Amplitude (a.u.) vs. Wavelength (nm)
In this talk we demonstrated the
- generation of sub 40 fs pulses
- effect of dispersion on short pulses
- advantage of interferometric autocorrelation
- advent of sophisticated measurement techniques
Conclusion & Outlook

In this talk we demonstrated the
  • generation of sub 40 fs pulses
  • effect of dispersion on short pulses
  • advantage of interferometric autocorrelation
  • advent of sophisticated measurement techniques

Future research will involve
  • optimization of dispersion compensation
  • complete characterization of pulse profiles
  • physics of ultrafast pulses
I would like to acknowledge contributions to this research by the following people:

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