Physics 430/530 Semester Project

Ultrafast Pump-Probe Laser System

The purpose of this project is for each person to gain experience in designing part of a femtosecond laser system for pump-probe experiments. The system diagram is provided below and in block form as a Powerpoint file. The parts are described below and you must provide a cost estimate for their part and explain in detail (part no., company) how to mount and position the equipment in their part on a laser table. Each team must also discuss what alternatives they considered and why the alternatives were rejected. The class as a whole must provide a scale top view and side view of a laser table with all components on the table to prove that the design is practical. The side view must show the height of the optical path above the table. If different parts of the optical path are at different heights, all must be shown. For each part, find at least one company not mentioned by us and tell us whether this company provides better- or worse- products than those references. The femtosecond laser system should provide 50- 100 MHz repetition rate of pulses. Each pulse should be 20 fs or shorter just out of the femtosecond laser, and 40- 50 fs (or shorter if possible) on sample. The laser system should be tunable between 700- 1000 nm wavelength, and with a doubling crystal (not shown in diagram) between 350- 500 nm wavelength. The parts include:

a. 1. Pump and femtosecond lasers

For the pump laser, compare an Ar+ ion and solid state pump lasers and a Ti:sapphire femtosecond laser. Briefly describe how each laser works and the important considerations for using the two lasers together. Look at the pump laser wavelength- how suitable is it to pump the femtosecond laser? Which is the best pump laser wavelength? What is the pump noise versus frequency? How will the pump laser output be coupled to the femtosecond laser? How will the femtosecond laser output be coupled to the next optical component? Consider light polarization, loss of laser power, vertical height, beam stability, and whether a telescope is needed to couple the two lasers. Consider what utilities are needed, included water, electrical power, compressed air, and room temperature. Company references: Pump Laser- Coherent, Spectra Physics. Femtosecond Laser- KMLabs, Inc.

b. 2. Common Prism Pair and 4. Pump Prism Pair

Explain the concept of group velocity dispersion and the purpose of a prism pair. Why do you need two prism pairs, one common to pump and probe beam and the other for the pump beam only? Explain the range of dispersion at different wavelengths. Consider power losses involved in using each prism pair. Company references: KMLabs, Inc. Literature references: A good reference on pulse dispersion can be found in "Lasers" by A. E. Siegman, Chapter 9: Linear Pulse Propagation. The negative dispersion of a prism pair is described in the paper "Negative dispersion using pairs of prisms", R. L. Fork, O. E. Martinez, and J. P. Gordon, Optics Letters, Vol. 9, No. 5, May 1984, pp. 150-152. I have used the Schott optical glass catalog and the Handbook of Optics to look up the Selmier coefficients for various materials.

c. 3. Beam splitter, acousto-optical modulator (AOM), function generator and CCD camera

The beam splitter provides both pump and probe pulses. A typical ratio is 10:1. What type of beam splitter would you use? Keep in mind that the pulses have a much higher power level during the pulse than the average power level. The acousto-optical modulator provides a modulation of the pump pulse used with a lock-in amplifier to obtain a signal- the change of optical reflectivity (measured by the reflection of the probe pulses). What modulation frequency would you use? What function generator would you use to provide the modulation frequency? The CCD camera is there to look at the sample and determine, as needed, the overlap between the pump and probe beams. The optical path from sample to camera is: sample – to- iris – to- lens –to- camera. There are two ways (at least) to do this: (i) buy a webcam camera and rip out the front lens, or (ii) buy a CCD camera with the correct focal length lens. Where will you place this CCD camera on the optical table. Company references: beam splitter: Thorlab, Newport, MellesGriot; AOM: Brimrose, Interaction; Function generator: Hewlett- Packard, Stanford Research Systems.

d. 5. Linear stage (with controller), retroreflector, infrared card, and infrared camera

The linear stage and retroreflector are used to vary the optical path length between the pump and probe beams: to change the time delay between the two pulses. An IR card (held in your hand) is used to stick into the beam as needed to see where the beam is. The IR camera is used for the same purpose, except that you can track the IR beam with the camera. How do you test and confirm that the linear stage and retroreflector work correctly? What features do you want the controller to have? In particular, do you prefer a computer and dumb controller, or a 'smart' controller? Company references: Retroreflector- Thorlab, Newport, Melles-Griot; Linear stage: Newport, Aerotech; IR card: Thorlab, Newport, Melles-Griot; IR camera: FJW Optical Systems.

e. 6. Half-wave plate, polarizer, optics and oscilloscope

The half-wave plate and polarizer are there to insure that the pump and probe beams have orthogonal polarizations, which reduces the effect of scattered pump light as background (noise on) to the signal. The optics are there to move the probe beam around. The oscilloscope is to examine the signals and beams. For what wavelengths is the half-wave plate actually a half-wave plate? How perfect is it as a half-wave plate? How much optical absorption? For the polarizer, what type is best? What extinction ratio should be used? For the oscilloscope, don't try to see the details of individual pulses. Instead, you do need to use a fast photodiode (which one? from what company?) to see the pulse train, with 5 ns time resolution (better if not much more costly).

f. 7. Input Probe beam optics, 8. Input Pump beam optics, 9. Cryostat and pump doubling crystal

Although the diagram shows a single lens for both pump and probe beam paths, you should design the system with separate lenses. The purpose of the optics is to focus the two beams onto the same spot on the sample, and to reduce scattered light. The purpose of the cryostat is to cool or heat the sample from 4.2K- 300K. The purpose of the pump doubling crystal is to change the pump beam from 700- 1000 nm to 350- 500 nm wavelengths. For the lenses and beam optics, we suggest buying a lens kit. Consider that, due to space limitations, you will probably use small lenses and non-standard mounting may be necessary. The lens kit should cover focal lengths of 7- 25 cm. The spot size of each beam on sample should be 50-150 microns. The probe spot size should be smaller than the pump spot size and remain within the pump spot as the sample temperature is varied. The pump power on sample should range from 50 mW to 0.25 mW. The pump doubling crystal setup should have an optical path of: pump beam- to- lens- to- doubling crystal- to- filter- to- iris- to- lens. Where will you place the doubling crystal assembly? Keep in mind that the pump beam path should be changed as little as possible- you don't want to have to realign the entire system when you change pump wavelengths. You must specify the components (e.g., focal length of lenses, which materials, part no. and company), how far apart the components are from each other, and where they are placed on the optical table when in use. The probe power on sample should be (1/10) the pump power. For the cryostat: Consider thermal expansion, stability, temperature and temperature range, liquid helium consumption (note that LHe costs $3-$4/liter), which optical window you want to choose, and what temperature controller to use. How will you move the cryostat, or the doubling crystal, in the x, y, or z directions? Company references: Beam optics- Thorlab, Newport, Melles-Griot; cryostat: Janis Corp., Oxford Instruments; XY(maybe Z) mounts: Newport, Thorlabs.

g. 10. Doubling crystal and FROG

The doubling crystal (BBO is one material) is used to determine the time t= 0 (when the pump and probe arrive at the same time). Instead of a 90-10 beam splitter, you use a 50-50 beam splitter. When the two beams arrive at the same time, photons of energy = 2hυ are generated by second harmonic generation. Explain the science of how this works. The 'system' is simple. You place the crystal near (within 1-2 mm) of where the sample will be. Behind the crystal you place a card that glows when illuminated by 400 nm light, but does not glow when illuminated by 800 nm light. You turn off the lights in the room and look for a glowing spot. The FROG apparatus is used to measure the pulse profile in time. To use the FROG apparatus, the optical path is: pump (or probe) beam- tomirror inserted into beam- to- second mirror (two mirrors needed to adjust the beam) – to- iris – to- FROG (with iris inside FROG if possible). The one or two iris components are used to reduce scattered light. A lens may or may not (you tell us) be necessary. The computer controls the FROG apparatus. Which FROG apparatus, of what specifications, do you use? What thickness of doubling crystal 4 (of which material) do you use? Company reference: FROG: KMLabs, Inc. (which also has reference material on FROGs).

h. 11. Output optics, Photodetectors, Power meter(s) and Spectrometer

The output optics is to a pump beam stop and, for the reflected (or transmitted) probe beam, to a photodetector. Reducing scattered light here is essential. The photodetector can be complete or homebuilt. You must consider whether to use faster or slower photodiodes; each has advantages. The power meters are to check the power levels of each laser, and of each beam along the beam path to the sample. It may be necessary to use more than one meter. The measurements include the pump laser (5 watt, you tell us the wavelength), the femtosecond pump laser (From 500 mW out of the laser to 0.25 mW on sample) and the probe pulse (as low as 0.025 mW on sample). Note that the pump laser is a CW laser, but all other measurements are measuring pulses, so make sure the meter(s) can handle CW and/or pulses, depending on which one or ones you select. The spectrometer (not shown in diagrams) is to measure the intensity of the pump beam versus wavelength. It is best to have the spectrometer fixed on the optical table and monitoring the pump beam at all times. To do this, insert a 100:1 beam splitter and direct the weaker beam to the spectrometer. A lens may or may not be needed (you tell us). The computer controls the spectrometer. The spectrum allows you to see an incipient problem, such as the beginning of loss of mode locking. Company references: Photodetectors- Hamamatsu; Power metersCoherent, Spectra Physics, Newport; Spectrometer- Ocean Optics.

i.12. Lock-in and Computer

Lock-in: Use an audio or RF lock-in? What is the dynamic reserve? What is the background noise level? What type of interface between the lock-in and the computer is best? In particular, should there be an ADC between the lock-in and the computer (why or why not)? Between the photodetector and lock-in, do you want a pre-amplifier, with or without a bandpass filter? What type of interface should be between the function generator and the lock-in (the function generator provides the lock-in reference signal)? How do you measure both the AC and the DC reflectivity levels of the reflected (or transmitted) probe beam? Computer: Inputs are: Lock-in (3 inputs, including AC phase, AC amplitude and DC amplitude), CCD camera (1 input), FROG (1 input), Spectrometer (1 input), and Linear Stage (1 input). There is one output: to the linear stage. What type of computer is needed? Is there an advantage to averaging the signal, say 10 or more times, during one step? If so, how would you do this? What program would you use to control the peripherals? Which computer bus would you use? Which components would you have on the bus? Company references: Lock-in: EG&G, Stanford Research Systems; Computer: the usual suspects. The optical layout schematic provides more details. We will provide information and references to get started on each part.