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A UV PUMP LASER SYSTEM FOR MICRO-UED AT CORNELL

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Abstract

Ultrafast electron diffraction (UED) probes the dynamics of material structures which are triggered by a fs pump laser pulse. Some materials of interest for UED study, such as wide-bandgap insulators, require the use of UV pump lasers. Furthermore, UED with a probe size on the single micron scale requires high stability in the position, power, and size of the pump laser, which demands feedback systems and real time monitoring integrated in the full accelerator control system. Here we discuss a system currently implemented at a UED beamline at Cornell University for producing, monitoring, and stabilizing a UV pump laser for UED with few micron probe beam sizes.

INTRODUCTION

Pump-probe experiments like ultrafast electron diffraction (UED) make use of the advances in generating sub-picosecond laser pulses to provide femtosecond temporal resolution for studying dynamics in materials [1–3]. In UED, a laser pulse denoted as the pump is used to excite the dynamics in the material, and an electron pulse denoted as the probe is used to study the resulting atomic motion via observing the electron diffraction pattern at different times after excitation. The pump triggers the dynamics by exciting the electrons, which then transfer the energy to the lattice via electron-phonon scattering. This requires that the pump laser energy be greater than the band gap of the material being studied.

A number of wide band gap materials show properties which are of interest for UED studies. Examples include antiferromagnetism in NiO [4], the formation of an antiferrodistortive phase in Ca doped $SrTiO_3$ [5], and the light induced swithching between different polar skyrmion structures in $(PbTiO_3)_n/(SrTiO_3)_n$ [6]. The pump laser used for studying these materials must have a wavelength at or below the UV spectrum in order to overcome their band gaps.

Creating a pump laser system capable of studying these materials can prove challenging due to the requirements on the stability and size of the pump laser. Pump-probe measurements require a constant pump laser fluence in the probed region of the sample. Additionally, some of the materials of interest are difficult to fabricate with dimensions greater than a few tens of microns. Consequently, a UV pump laser system capable of stabilizing the position and size of the pump laser on the single micron scale is necessary to study such materials with UED.

In this proceeding, we discuss a pump laser system we have built for a UED setup at Cornell University designed to study materials with large band gaps and crystal sizes down to the single micron scale [7]. This system was designed to stabilize a UV pump laser using detectors for visible light, which both reduces the overall cost of the system by removing the need for expensive UV compatible detectors, and allows the same system to function using a visible spectrum pump laser when desired.

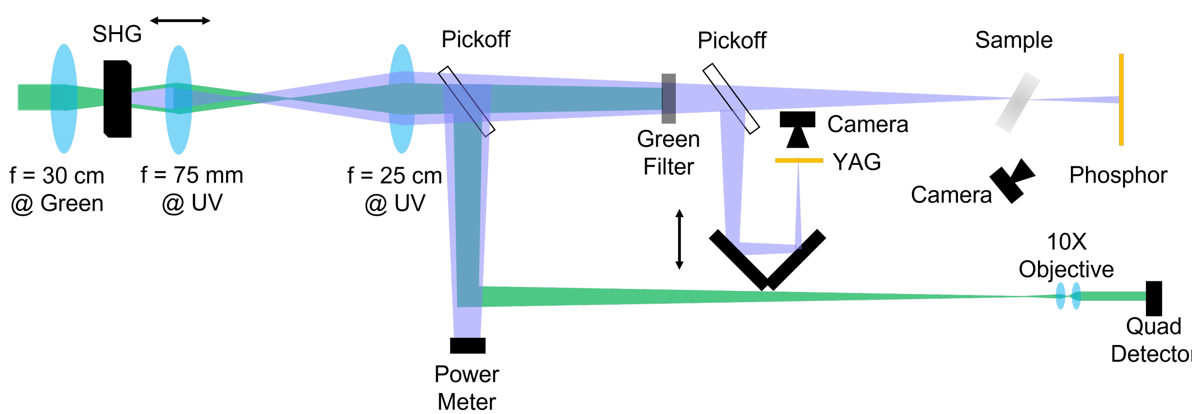

Figure 1: Diagram of pump laser control system. The incoming green laser is partially converted to UV via second harmonic generation (SHG). Part of the UV and residual green are picked off for position and power monitoring and feedback respectively. The remaining residual green is filtered out before a second pickoff diverts part of the UV for size and slow position control using a virtual sample consisting of a YAG screen monitored by a camera. Double-sided arrows indicate the optics are on a movable stage.

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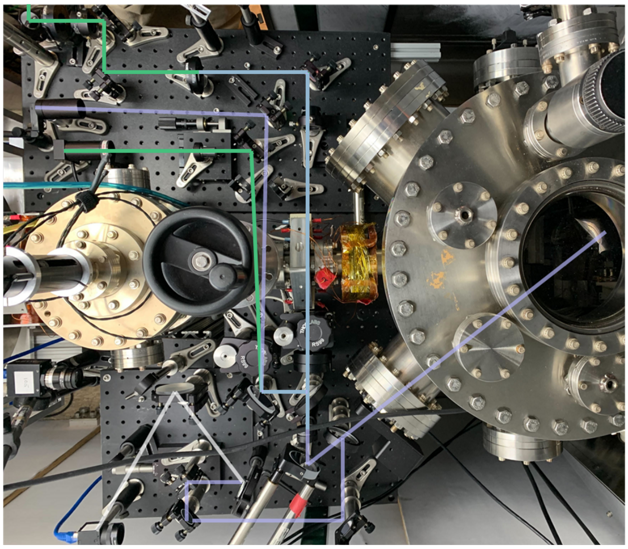

Figure 2: Photograph of the final section of the UV pump laser system. The overlayed lines indicate the path taken by the green laser (green lines), UV laser (purple lines) and both (light blue lines).

SYSTEM DESCRIPTION

In our system, a 1030 nm pulsed laser produced by an Amplitude Systèmes Yb fiber laser system is converted via second harmonic generation (SHG) into a 515 nm beam. This undergoes a second SHG process near the sample chamber to finally yield a pulsed 257 nm laser for pumping. Converting to UV near the sample chamber allows most of the laser transport to be done in green, which reduces the number of UV compatible optics needed. A telescope lens system immediately after the second SHG crystal is used to control the laser beam size on the sample. To stabilize and control the beam position, we use feedback systems on two different time scales, which we denote as fast and slow. Following the telescope, a beam sampler diverts approximately 5% of both the UV and the residual green laser which are used for power and fast position feedback respectively. Along the main path, the residual green laser is filtered out, and a second beam sampler diverts another 5% of the laser for slow position and size control. See Figs. 1 and 2 for details.

Fast Position Feedback

The fast position feedback system consists of a Thorlabs PDQ80A quad detector modified to work on pulsed beams. This detector is not designed to detect UV light, therefore we pick off part of the residual green laser to be monitored by this detector. A POLARIS K1S2P mount which comes equipped with piezo actuators feeds back on the quad detector and adjusts a mirror mounted on it to compensate for laser position jitter. The pump laser is focused on the sample, so the quad detector must correct the picked off green laser at its focus, which notably is not at the same distance from the beam sampler as the sample. Additionally, due to the small size of the residual green laser, the quad detector is unable to reliably correct for jitter when placed at the green lasers focus, so an additional telescope lens is necessary to create a magnified image of the focused beam on the quad detector.

Slow Position and Size Feedback

In addition to the fast laser position feedback system, we have a slow position control system. This allows us to better compensate for position drifts on the hour scale as well as moving the laser on the sample. This system consists of an Allied Vision GC650 camera focused on a YAG screen which fluoresces in the visible when illuminated with UV. The YAG screen is located at an equal distance from the second beam sampler as the sample and therefore serves as a virtual sample. A set of Newport TRA25CC actuators controls a mirror located after the first beam sampler which allows for position control on the sample without interrupting the jitter control. Using this setup, we can also monitor the variation of the pump laser position, which we found to be ±2 μm RMS.

Along with controlling the position of the pump laser on the sample, this image is also used to control the size of the pump laser on the sample. This is done via a stage that moves the longitudinal position of a lens in a telescope system soon after conversion to UV, see Fig. 1.

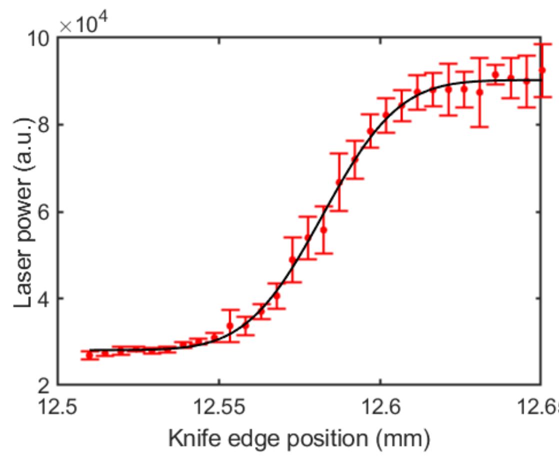

Figure 3: Knife-edge measurement of pump laser beam size at the sample location. The measured RMS laser size is 18.5±0.7 μm.

Transmission Monitoring

Spatial alignment of the pump and probe beams is done by comparing the transmission of the two through the sample. The pump beam transmitted through the sample is incident on a phosphor screen. This screen is monitored by a camera outside the sample chamber through a window. By scanning the sample horizontally and vertically, transmission maps of the sample are obtained using both the pump and probe beams. These are compared to ensure the beams are spatially overlapped.

This transmission monitoring setup also allows us to perform knife-edge measurements of the pump laser beam size

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as showing in Fig. 3. We found we can achieve transverse pump laser sizes below 20 µm RMS, and repeated measurements showed a variation in size of ±1 µm.

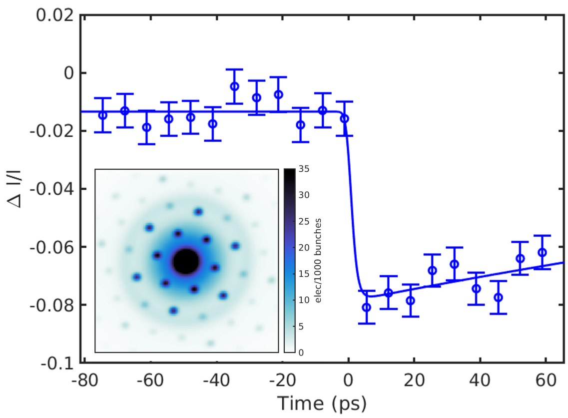

Figure 4: Time series showing the intensity modulation of the second order diffraction peaks from WSe_2 due to the Debye-Waller effect. Inset shows an example of difference image where the diffraction image taken before the pump laser arrival ($t < 0$) is subtracted from the diffraction image taken after pump laser arrival (t > 0).

PUMP LASER SYSTEM VALIDATION

In order to test the functionality of the UV pump laser system, diffraction difference images were created for different pump laser arrival times with respect to the probe electron beam on a WSe_2 monolayer sample. When the probe electron beam arrives at the sample shortly after the pump laser, the resulting diffraction pattern is modified relative to the static diffraction pattern due to the heating of the lattice by the pump laser, known as the Debye-Waller effect [8, 9]. The magnitude of the modulation of each diffraction peak is determined by the material properties as well as the pump laser fluence. Thus, by averaging over many diffraction difference images, the stability of the pump laser fluence on the sample, determined by the overall laser power, size, and position stability can be in part interpreted from the magnitude and error of the depth of modulation of the diffraction peak intensity. A plot of the intensity modulation in the second order peak for different arrival times of the pump laser is shown in Fig. 4.

CONCLUSION

We have constructed a system for producing, monitoring, and controlling a UV laser for UED experiments. To achieve this, we have successfully adapted equipment designed to work in the visible spectrum. We tested the stability of the UV pump laser system by performing knife-edge measurements of the laser size and monitoring the position of the beam on a virtual sample. We found both laser position and size are stable on the single micron scale. The knife-edge measurements also showed we were able to focus the pump laser to less than 20 µm as required for studying some materials with dimensions on the same scale. To validate the functionality of our system, we pumped a WSe_2 monolayer and measured the Debye-Waller effect.

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