FEMTOSECOND LINAC-LASER BASED TIME-RESOLVED X-RAY DIFFRACTOMETRY FOR VISUALIZATION OF ATOMIC MOTIONS

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Abstract

We carried out the time-resolved X-ray diffraction experiment where 100fs 3TW laser and 10ps X-rays are used as pump-and probe-pulses, respectively. We used the synchronized femtosecond electron linac and laser system. Using 10ps Cu $K\alpha_{1,2}$ X-ray pulses via collision between 10ps electron beam and a Cu wire, we could obtain diffraction images from several monocrystal semiconductors(Si, GaAs, Ge), ion-crystals(NaCl, KCl) and alkalihalides (CaF_2, BaF_2). However, the change of the X-ray diffraction image could not be observed because of surface damage due to repeated laser irradiation. In order to get more X-ray photons and perform single-shot pump-and-probe analysis, we are going to proceed to laser plasma X-ray based analysis.

1 INTRODUCTION

Synchronized femtosecond electron and laser beams can be generated and measured at Nuclear Engineering Research Laboratory, University of Tokyo[1,2,3]. Those primary femtosecond beams are converted to far-infrared coherent radiation and X-ray pulses via transition radiation and collision with metal targets, respectively. Thus we can perform ultrashort quantum beam based pump-and-probe analysis to investigate ultrafast beam-matter interactions. Here atomic motions in nonequilibrium thermal expansion, ablation, phase transition, soft-mode phonon are expected to be observed as snapshots of X-ray diffraction images. We proposed the new time-resolved X-ray diffractometry where ultrashort X-rays via electron-metal collision is used as a probe pulse[4]. X-ray diffraction images from several monocrystals using 10ps Cu $K\alpha_{1,2}$ X-rays are presented and future subjects to be overcome are mentioned.

2 LINAC BASED EXPERIMENT

Experimental configuration is depicted in Fig.1. 35MeV, 10ps(FWHM), 1nC electron single bunch was irradiated with the $100\mu m^t$ Cu wire to generate Cu $K\alpha_{1,2}$ X-rays(8.048, 8.028keV). Generation of 10ps Cu $K\alpha_{1,2}$ X-rays was confirmed by the numerical analysis using EGS4 code[4]. The 100fs 3TW Ti:Sapphire laser[5] was used as a pump pulse to induce nonequilibrium thermal expansion. Here the linac-laser synchronization system[1] was used to control the delay time of the probe-X-rays from the pump-laser.

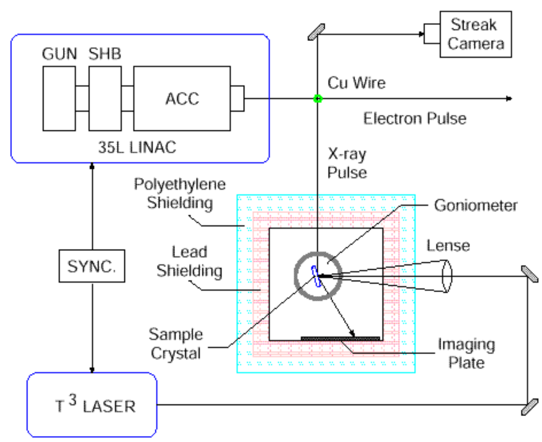

Figure 1: Configuration of the linac-based experiment.

We used monocrystal semiconductors of Si(111), GaAs (111), Ge (111), ion crystals of NaCl (200) KCl(200) and monocrystal alkalihalides CaF_2(220), BaF_2(111). X-ray diffraction image is drawn on an X-ray imaging plate set in the noise-radiation shielding box. Laser energy per shot is 68mJ. The number of photons of the X-ray per shot is estimated to be about 10^6. Due to the limited solid angle at a specimen, only about 1/100 of them reach the specimen. Thus, we need 10^4-10^5 times repetition for the pump-and-probe shot. Cu $K\alpha_{1,2}$ X-ray diffraction images from all specimens were successfully obtained. The pump-and-probe analysis was carried out for a GaAs specimen. However, its surface suffered laser-irradiation damage before the X-ray diffraction image for deformed lattice was obtained. Photograph of the damaged GaAs specimen and the Cu $K\alpha_{1,2}$ X-ray diffraction images influenced by the damage are shown

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in Fig.2. The damage may attribute physical ablation or photo-chemical reaction with air.

Let us clarify the characteristics of the electron linac based X-ray diffractometry. Based on the numerical analysis by EGS4, subpicosecond Cu K$\alpha_{1,2}$ X-rays can be surely produced. However, due to lack of photon numbers, we need many times pump-and-probe shots to get the X-ray diffraction image. In this case, the phenomena to be observed have to be nondestructive. If the phenomena is destructive, we should choose the TW laser plasma based one.

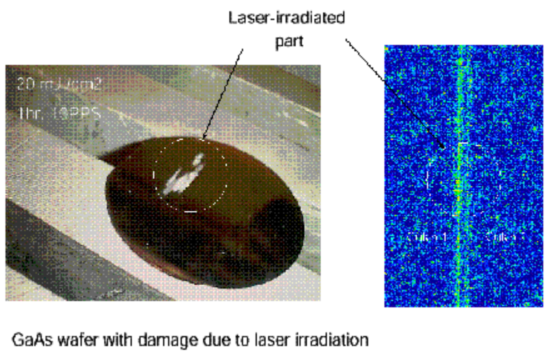

Figure 2: GaAs specimen with damage and K$\alpha_{1,2}$ X-ray diffraction image.

3 TW FS LASER BASED EXPERIMENT

When a TW fs laser is irradiated at a Cu plate, the ablation occurs and the plasma is generated. Then hot electrons over 10keV are also produced there. These electrons can induce Cu K$\alpha_{1,2}$ X-rays. The main advantage of this process is a large number of X-rays photons as about 10^{11} per shot, while the drawback is its long pulse width as a few ps[7]. In this case, it is expected that one laser-and-X-ray irradiation is enough to get a diffraction image. We carried out Cu K$\alpha_{1,2}$ X-rays generation via this process using the 2TW 100fs laser light. The generation was confirmed by depicting the characters of "LPX" on the image plate as shown in Fig.3. We are going to use the laser induced plasma X-rays in the next step.

4 NUMERICAL ANALYSIS

We are developing a computer code to calculate the change of Cu K$\alpha_{1,2}$ X-rays diffraction image due to atomic motions. We have already calculated the images of deformed lattices under several assumptions. Then, we are going to calculate the change of the image due to realistic nonequilibrium thermal expansion, phase-transition and soft-mode phonon. By using this code, we plan to perform an inverse analysis to evaluate deformed lattice from measured X-ray diffraction images in the pump-and-probe analysis. The final goal is the animation of the atomic motions via computer graphics.

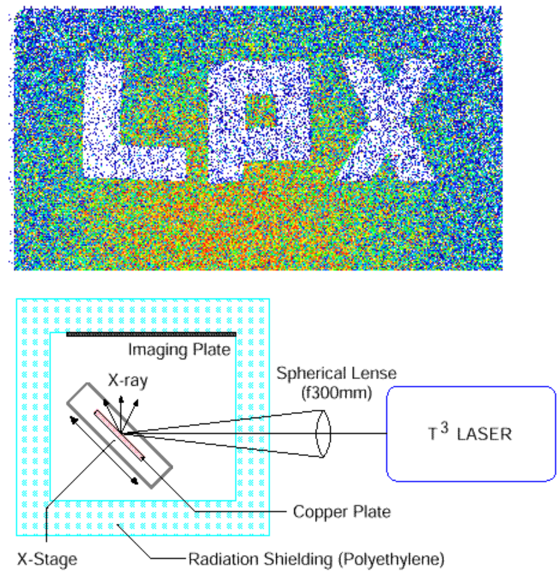

Figure 3: Configuration of the TW FS laser based experiment and result.

5 FEMTOSECOND ULTRAFAST QUANTUM PHENOMENA RESEARCH FACULTY

The titled facility is going to be installed in the laboratory. Here the upgraded femtosecond S-band twin linacs with 100fs stable Kerr-lens-model-locked Ti:Sapphire laser, 12TW50fs laser, X-ray diffraction analysis devices, the X-ray electron spectroscopy device and the Fourier transform infra-red spectroscopy device are introduced as shown in Fig.4.

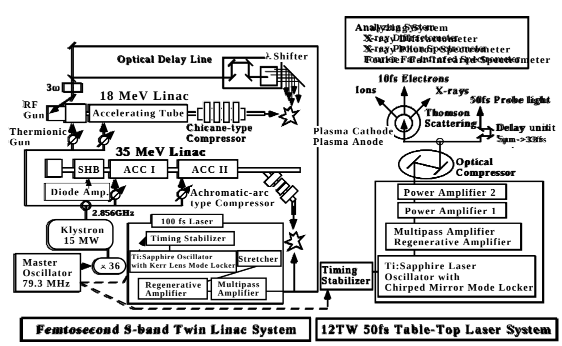

Fig.4 Femtosecond ultrafast quantum phenomena research facility.

Hundreds fs time-resolved pulseradiolysis for radiation chemistry is available using the first, while several basic researches of tens fs beam (electron, ion, X-rays) generation are performed via plasma cathode, plasma anode and relativistic nonlinear Thomson scattering using the second. After we have succeeded in the generation experimentally, we can proceed to a variety of tens fs time-resolved pump-and-probe analyses.

6 CONCLUSION

10ps Cu K$\alpha_{1,2}$ X-rays was generated via 10ps elections-Cu wire collision using the electron linac. Cu K$\alpha_{1,2}$ X-rays diffraction images were obtained for several monocrystals. Further, we produced picoseconds laser plasma Cu K$\alpha_{1,2}$ X-rays via 2TW 100fs laser-Cu plate irradiation. In order to get X-ray diffraction images from deformed lattices in laser-induced nonequilibrium thermal expansion by single pump-and-probe shot, we plan to use the new 12TW 50fs laser in the next step.

7 REFERENCE

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