TECHNICAL DEVELOPMENT OF PROFILE MEASUREMENT FOR THE SOFT X-RAY VIA COMPTON BACKWARD SCATTERING

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Abstract

A compact X-ray source is required by such various fields as material development, biological science, and medical treatment. At Waseda University, we have succeeded to generate the soft X-ray of the wavelength within so-called water window region (250-500eV) via Compton backward scattering [1, 2] between 1047nm Nd:YLF laser and 4.6MeV high quality electron beam. Although this method equips some useful characters, e.g. high intensity, short pulse, energy variableness, etc, the X-ray generating system is compact enough to fit in tabletop size. In the next step, there rises two principal tasks; To make the soft X-ray intensity higher, 2-pass amplifier was utilized. To progress X-ray profile measurement techniques as preliminary experiments for biomicroscopy, we planned to irradiate X-ray to a resist film which is previously exposed by UV-lamp or get images with X-ray CCD. In this conference, we will show the experimental results and some future plans.

COMPTON BACKWARD SCATTERING

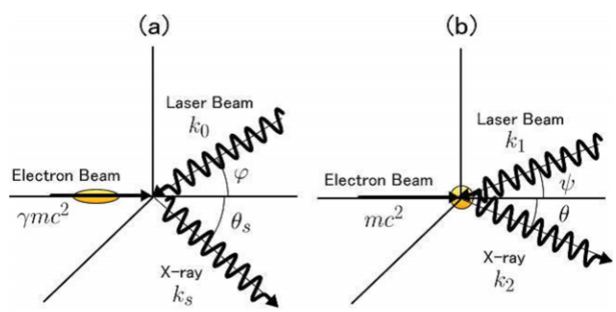

Figure 1: The coordinate of scattaring between laser beam and electron beam in (a) laboratory frame and (b) electron rest frame.

Low energy photons, which collide with high energy electrons, get energy and are scattered as X-ray. The direction of energy transfer is the opposite of general Compton scattering, so it is called 'Compton backward scattering'. Figure 1 shows the coordinate of scattering between laser beam and electron beam in laboratory frame and electron rest frame, where it is assumed that electron beam energy and incident photon energy are γmc^2 and k_0 in laboratory frame. Then, the scattered photon energy k_s is given by

$$k_s = \frac{\gamma^2 k_0 mc^2 (1+\beta\cos\varphi)(1-\beta\cos\theta)}{mc^2 + (1-\cos\theta)(1+\beta\cos\varphi)\gamma k_0} \quad (1)$$

, where $\cos\theta = (\cos\theta_s - \beta)/(1-\beta\cos\theta_s)$ and angles of $\varphi, \theta, \theta_s$ are the scattering angle in laboratory frame, the scatterd angle in electron rest frame and in laboratory frame, respectively. According to Equation (1), we note that k_s can be chosen arbitrarily for variety of the scattering angle φ.

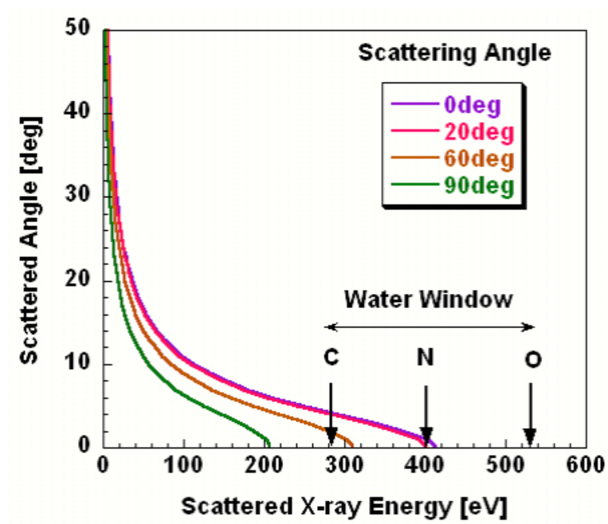

Figure 2: Angular distribution of generated X-ray at different scattering angle.(The electron beam energy is 4.8MeV.)

We chose 1047nm for the wavelength of laser beam, 4.6MeV for the energy of electron beam. The angular distribution of scattered photon energy at various scattering angles is shown in Figure 2. When 20 deg is chosen for the scattering angle, the maximum photon energy become about 370eV, which is included in 'water window region' [3]. There are K-shell absorption edges of Oxygen, Carbon and Nitrogen within the region, so the X-ray is absorbed mainly by such as protein, which composes a living body, rather than water. If we only use the forward X-ray, the X-ray become quasi-monochromatic and is applicable to the biomicroscopy.

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X-RAY GENERATION

Experimental Setup

Figure 3 shows the X-ray generation system at Waseda University. Laser beam (Nd:YLF, 1047nm) passed through a flash lamp amplifier and a delay stage. In order to make the X-ray intensity higher than previous experiments, the laser passed the amplifier twice (two-pass amp) so that the energy is increased to about 10 mJ/pulse. The delay stage was used to control the timing between laser beam and electron beam. On the other hand, electron beam (4.6MeV) was generated from photocathode RF-gun, which was using the UV laser (262nm). Both IR laser and UV laser originated from the same laser system, thus IR laser and electron beam synchronized precisely. Electron beam was compressed by a solenoid magnet and quadrupole magnets, and collided with laser beam at 20 deg of the scattering angle. After the collision, electron beam was separated from X-ray by a bending magnet. The generated X-ray was detected with MCP (Micro Channel Plate).

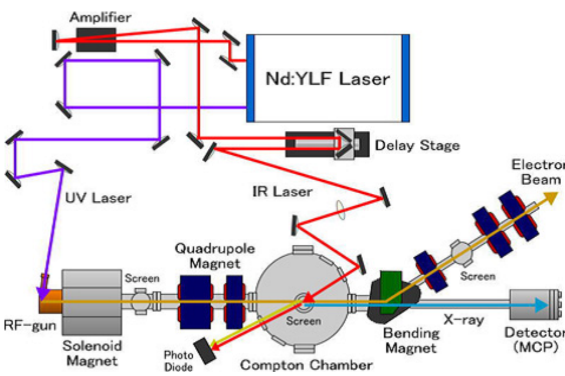

Figure 3: X-ray generation system.

The laser beam parametes and the elctron beam parametes are given in Table 1 and 2, respectively.

Table 1: Laser beam parameters.

Wavelength	1047 nm
Energy	10 mJ/pulse
Beam size σ_x	80 μm
Beam size σ_y	80 μm
Pulse width	10 ps (FWHM)
Repetition rate	5 Hz

Table 2: Electron beam parameters.

Beam energy	4.6 MeV
Bunch charge	600 pC
Beam size σ_x	280 μm
Beam size σ_y	250 μm
Bunch length	10 ps (FWHM)
Repetition rate	5 Hz

Results and Discussions

When laser beam passed through the amplifier once (1-pass amp) or twice (2-pass amp), MCP signal was about 170mV and 400mV (Figure 4), and total number of the generated X-ray phtons was calculated as 5.2×10^3 [4] and 1.2×10^4 [5], respectively. From the above, we noted that, when the amplification of the laser beam was increased, the X-ray intensity became higher.

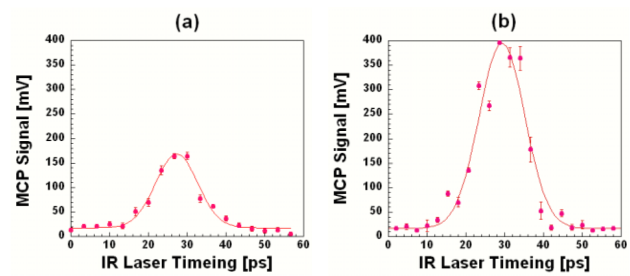

Figure 4: X-ray signal (a) with 1-pass amp and (b) with 2-pass amp.

UV PRE-IRRADIATION EXPERIMENTS

To realize the soft X-ray biomicroscope via Compton backward scattering, we tried to get X-ray profile with resist film at first. Irradiating X-ray to resist film (for Deep-UV, PMMA base) and baking it, chemical reaction is caused within the irradiated area. Profile of the X-ray will be taken by developing the film. The resist film could not be exposed to X-ray in practice, because the X-ray has several handreds of photons per pulse. To confirm the threshold exposure dose of the resist, sensitivity curve was obtained with UV-lamp (254nm, $5\mu W/cm^2$), and it turned out to be about 250 $\mu J/cm^2$ (Figure 5).

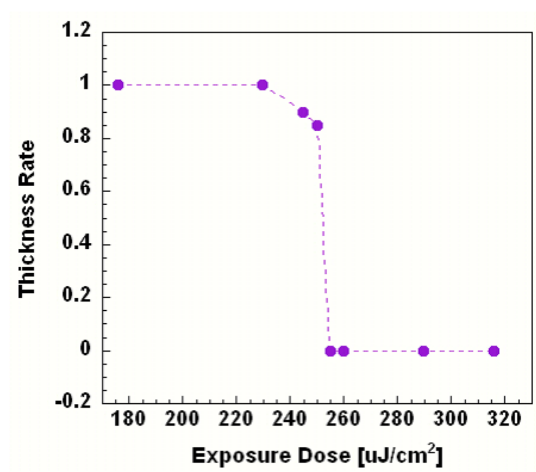

Figure 5: Sensitivity curve of resist film.

To decrease the required X-ray exposure dose, 'UV pre-irradiation method' was designed; After exposure dose around threshold is given by UV-lamp (pre-irradiation), the

X-ray is irradiated (post-irradiation). First of all, we done the test experiments; UV-lamp was utilize for both pre-irradiation and post-irradiation.

Results and Discussions

The result of the experiments is shown in Figure 6. When pre-irradiation dose was 230 $\mu J/cm^2$ or 250 $\mu J/cm^2$, the post-irradiation dose, which was necessary to dig the resist film completely, became reduced to the one fifth of the total required dose or the one thirteenth of it, respectively.

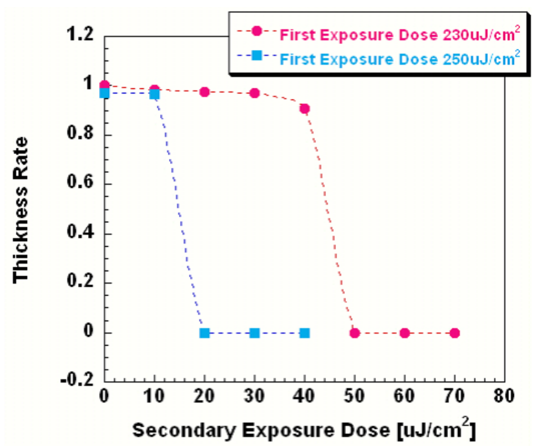

Figure 6: Result of UV pre-irradiation test exeperiments.

X-RAY BACKGROUND STUDIES

In order to get the X-ray profile in realtime, the soft X-ray CCD will be introduced. We have already prepared the CCD (Back-illuminated type, 512 x 512, 24 μm x 24 μm).

We assumed that the background of electron beam originated from the collision inside of beam pipe at the bending magnet. The background, which is consists of hard X-ray and so on, will not only hide the soft X-ray signal via Compton backward scattering, but also damage to the CCD device.

Experimental Setup

To reduce such background, we intended to compress the electron beam by quadrupole magnets. The experimental setup was slightly changed and one quadrupole magent was added (Figure 7).

We think that Qmag-C (the quadrupole magnet just before the bending magnet) will be effective against the background. Both Qmag-A and Qmag-B will be moved away from the collision chamber to decrease the background furthermore, because the electron beam, which is compressd within the longer distance, will not spread widely.

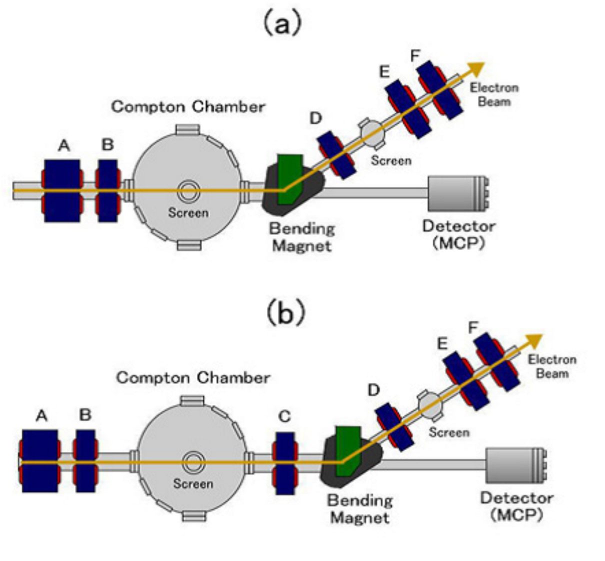

Figure 7: Setup of quadrupole magnets (a) before arrangemnt and (b) after arrangement.

CONCLUSIONS

At Waseda University, we have generated the soft X-ray via Compton backward scattering (explained in the first section). In the second section, we could make the X-ray intensity higher with 2-pass amplifier.

In the third section, 'UV pre-irradiation method' was introduced to expose the resist film. When pre-irradiation dose was 230 $\mu J/cm^2$ or 250 $\mu J/cm^2$, the post-irradiation dose became the one fifth of the total required dose or the one thirteenth of it, respectively. Using this method, we will actually irradiate the X-ray to the resist film.

Furthermore, X-ray CCD will be mounted to obtain its profile. In the fourth section, We have made plans to cut down the background and have contrived new setup of quadrupole magnets.

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