

ABSORPTION SPECTROSCOPY USING HIGH-INTENSITY COHERENT RADIATION FROM SHORT ELECTRON BUNCHES OF A LINAC*

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Abstract

The coherent radiation emitted from a high-energy short electron bunch has a continuous spectrum in a submillimeter to millimeter wavelength range. A high-intensity light source has been established by using the coherent transition radiation from single-bunch and multi-bunch electron beams of the L-band linac in Osaka University. The coherent radiation has been transported out from the accelerator room. The output light from a grating monochromator has been used in the measurement at wavenumbers about 10 cm^{-1} . It has been applied to absorption spectroscopy for liquid water and to imaging for relatively thin matters.

1 INTRODUCTION

The coherent transition and synchrotron radiation emitted from a high-energy electron bunch is relatively intense and has a continuous spectrum in a submillimeter to millimeter wavelength range. It has been applied to absorption spectroscopy [1,2].

High-intensity single-bunch and multibunch electron beams are generated with a 38 MeV L-band (1300MHz) linac [3] at the Institute of Scientific and Industrial Research in Osaka University. A coherent radiation light source has been established by using the beams [2,4] and absorption spectroscopy for N_2O gas has been carried out [2]. It can be applied to absorption spectroscopy at a relatively high wavenumber resolution for matters which strongly absorb light transmitting through them. Another possible application is stroboscopic pulse-radiolysis [5] using a picosecond short electron bunch and the coherent transition radiation emitted from the bunch.

The absorption of light in liquid water in a submillimeter to millimeter wavelength range is relatively strong. There have been only a few experiments on absorption spectroscopy for water [6-8]. In the present work a new system for absorption spectroscopy using a coherent transition radiation light source is established and it is applied to a water sample and to imaging experiments.

2 PROPERTIES OF THE COHERENT RADIATION

The spectrum of the coherent radiation emitted from an

electron bunch is approximately written by $p(\lambda) N^2 f(\lambda)$, where λ is the wavelength, $p(\lambda)$ the intensity of radiation from an electron, N the number of electrons in the bunch. The bunch form factor $f(\lambda)$ is given by the Fourier transform of the normalized distribution function of electrons in the bunch. At sufficiently long wavelengths compared with the bunch length, $f(\lambda)$ is nearly equal to 1. For the electron bunch of the linac in Osaka University N is 10^9 - 10^{11} and the bunch length is 20-30 ps which corresponds to 6-9 mm. The energy of the synchrotron radiation obtained by a single electron bunch at a charge of 30 nC was above 1 mJ at a wavenumber of 10 cm^{-1} in 1% band width [2]. Recently, light sources at wave frequencies in a terahertz region using the radiation from the photoconductive current switched with a pulsed laser have been developed. They are being applied to absorption spectroscopy. The peak intensity and the averaged intensity of the coherent radiation are much higher than those of the terahertz light sources.

3 EXPERIMENTAL METHOD

The linac has a composition optimized to generate the high-intensity picosecond single-bunch beam. Main components are a thermionic triode gun, three subharmonic pre-bunchers (two at an rf frequency of 108 MHz and one at 216 MHz), two fundamental bunchers at 1300 MHz, and an accelerating waveguide. The multibunch beams are also generated at macropulse lengths from 5 ns to 2 μs in the different operational conditions of the gun and the rf components. The maximum repetition rate of the pulsed rf is 120 pulses/s.

In the present experiment the multibunch beam from the linac is used. The beam energy is 27 MeV, the macropulse length 8 ns with a micropulse spacing of 0.77 ns, and the pulse repetition rate 10 pulses/s. The operational conditions of the linac are adjusted so as to generate relatively stable and intense radiation. The detailed operational conditions of the linac are described in ref. 9.

The experimental setup for absorption spectroscopy is schematically shown in Fig. 1. A thin Al plate as an emitter of the coherent transition radiation is installed in the transport tube of the electron beam. A ceramic plate as a beam-profile monitor is placed on the back side of the plate. The electron beam is focused on the plate with the quadruple magnets, where the beam diameter is about 2 mm. The coherent transition radiation emitted from the Al plate passes through a vacuum window of a wedged quartz plate. The output light is transported by using gold-coated plane and concave mirrors out from the accelerator

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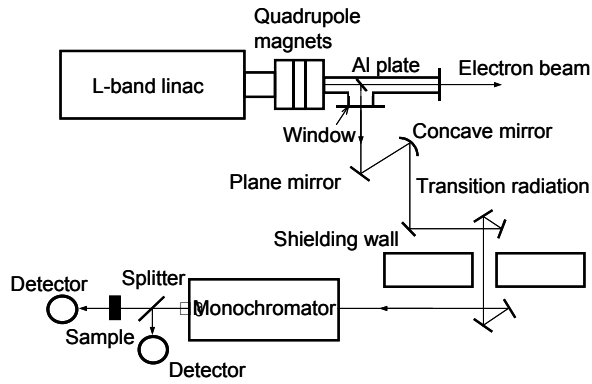


Figure 1: Schematic diagram of the experimental setup for absorption spectroscopy.

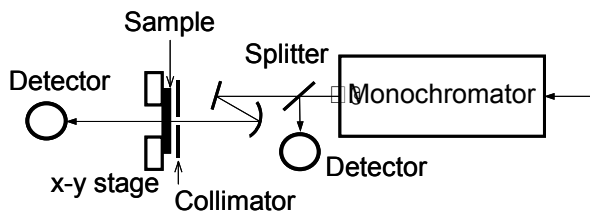


Figure 2: Schematic diagram of the experimental setup for imaging.

room to a grating monochromator. The output light from the monochromator is used for absorption spectroscopy and imaging experiments. The intensity of light is measured with liquid-He-cooled Si-bolometers which have a time resolution of about 0.5 ms. The sensitivity of the detector is calibrated with a high-temperature mercury lamp. The pulsed output signal of the detector is monitored with an oscilloscope. The wavenumber resolution in the spectroscopy is 1%. The resolution is comparatively large and the interference effect due to the use of the multibunch beam [10] is negligible in the present experiments. A part of the output light from the monochromator is reflected by a splitter to the detector. The distribution in the data of the intensity of light remaining after the compensation of the fluctuation in the intensity of the incident light measured by using the splitter has been $\pm 2.3\%$.

In the absorption spectroscopy for liquid water, the peak values of the pulsed signal of the detector are averaged over 20 pulses. Distilled and then deaerated water is used as a sample. The sample and spacers which fix the thickness of the sample are sandwiched with two anhydrous quartz plates 3 mm thick. The thickness of the water sample is 0.186 ± 0.003 mm. The sample holder is installed in a copper block, in which the temperature of the sample can be changed. In this experiment the temperature of the sample is 22 °C.

The experimental setup for the imaging experiments is shown in Fig. 2. The output light is collimated using a

collimator with a hole. The sample holder on the x-y stage is moved with pulse motors.

4 RESULTS AND DISCUSSION

The intensity of light transmitted through the sample and the holder plates has been measured in a wavenumber range of 10-14.2 cm^{-1} . The results are shown in Fig. 3. The periodic oscillation observed on the spectrum is due to the interference between lights passing in the sample and the holder plates. The incident light is reflected at each surface of the plates or at the boundaries between the different materials. The absorption coefficient and the refractive index of the sample have been obtained by analyzing the behavior of light and by using the Kramers-Kronig relation [11], as shown in Fig. 4. The error in the data is $\pm 2.8\%$. These well agree with the data previously obtained while the wavelength resolution is much higher in the present experiments.

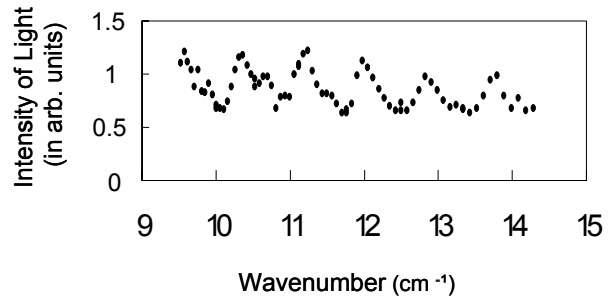


Figure 3: Spectrum of light transmitted through a water sample 0.186 mm thick and holder plates 3 mm thick.

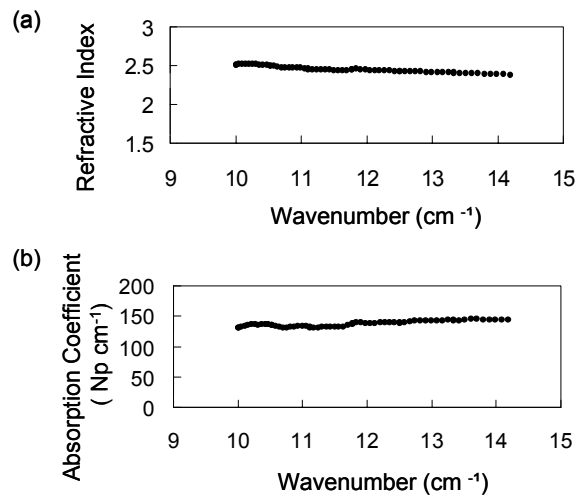


Figure 4: The refractive index (a) and the absorption coefficient (b) of liquid water at a temperature of 22 °C obtained from the results for the measurement.

In this work a new system for the absorption spectroscopy has been established. This system is being utilized for absorption spectroscopy for liquid water in the

wider wavenumber range at different temperatures. Imaging experiments at a certain wavenumber and pulse radiolysis experiments using the pulsed coherent radiation and the single-bunch electron beam are being performed.

5 CONCLUSIONS

A new system for absorption spectroscopy using the coherent transition radiation light source was established with the electron beams of the L-band linac. The output light from a grating monochromator was used for the spectroscopy for liquid water at a temperature of 22 °C. In the measurement the wavenumber range is 10-14.2 cm⁻¹ and the wavenumber resolution is 1%. The absorption coefficient and the refractive index of water were obtained. Imaging and pulse radiolysis experiments using the pulsed coherent radiation and the single-bunch electron beam are being performed.

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