Application of a submillimeter to millimeter wave light source using the coherent transition radiation to absorption spectroscopy for liquid water

Makoto Takanaka[a], Mitsumi Nakamura[a], Shuichi Okuda[a,*], Ryukou Kato[a], Toshiharu Takahashi[b], Soon-Kwon. Nam[c]

[a]*The Institute of Scientific and Industrial Research, Osaka University, 8-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan*

[b]*Research Reactor Institute, Kyoto University, Kumatori, Sennan, Osaka 590-0494, Japan*

[c]*Department of Physics, Kangwon National University, Chunchon Kangwon-do 200-701, Korea*

Abstract

A new system for absorption spectroscopy with a coherent radiation light source has been established by using the coherent transition radiation from the electron beams of the 38 MeV L-band linear accelerator. The coherent radiation has a continuous spectrum in a submillimeter to millimeter wavelength range. The output light from a grating monochromator has been transmitted through a sample of liquid water 0.186 mm thick at a temperature of 22 ℃. The intensity of the transimitted light has been measured in a wavenumber range of 10-14.2 cm^{-1} at a wavenumber resolution of 1%. From the results the absorption coefficient and the refractive index of water have been obtained.

1. Introduction

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

At the Institute of Scientific and Industrial Research (ISIR) in Osaka University, high-intensity single-bunch and multibunch electron beams are generated with a 38 MeV L-band (1300MHz) linear accelerator (linac) [3]. A coherent radiation light source has been established by using the beams [2,4,5]. 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 and are being applied to absorption spectroscopy. The peak and averaged intensity of the coherent radiation at ISIR is much higher than that of the terahertz wave light sources while these light sources cover nearly the same wavelength region. Hence, the coherent radiation is expected to be applied to absorption spectroscopy at a relatively high wavenumber resolution for matters with relatively strong absorption of light. Moreover, it is possibly applied to the pulsed excitation of matters.

The absorption of light in liquid water in a submillimeter to millimeter wavelength range is relatively strong. There have been only a few experiments of absorption spectroscopy for water [6,7]. In the present work a new system for absorption spectroscopy with a coherent radiation light source is established. The refractive index and the absorption coefficient of water are measured at a relatively high wavenumber resolution.

2. Properties of the coherent radiation

The spectrum of the coherent radiation emitted from an electron bunch is 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 wavelengths sufficiently longer than the bunch length, $f(\lambda)$ is nearly equal to 1. For the electron bunch of the ISIR linac N is 10^9-10^{11} and the bunch length is 20-30 ps which corresponds to 6-9 mm. The coherent radiation is highly intense and is a picosecond pulsed light. In the case of the multibunch beam the interference between the pulsed radiation from each electron bunch gives periodical oscillation on the spectrum [8]. This restricts the wavenumber resolution in spectroscopy using the radiation.

3. Experimental method

In the present experiment the multibunch beam from the ISIR 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 5.

The experimental setup for absorption spectroscopy is schematically shown in Fig. 1. A thin Al plate is installed in the transport tube of the electron beam as an emitter of the coherent transition radiation.

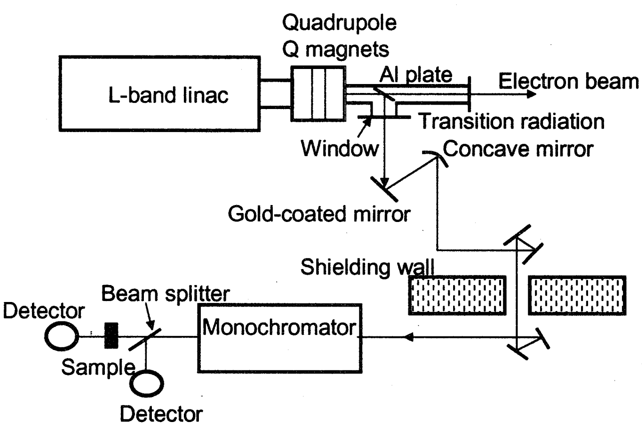

Fig. 1 Schematic diagram of the experimental setup.

A ceramic plate is placed on the back side of the plate as a beam-profile monitor. The electron beam is focused on the plate with the quadruple magnets, where the beam diameter is about 2 mm. In this configuration the beam position on the plate is not affected by the energy change of the electron beam, which makes the intensity of radiation relatively stable. The coherent transition radiation emitted from the Al plate passes through a vacuum window of a wedged quartz plate. The light is transported by using gold-coated plane and concave mirrors out from the accelerator room to a grating monochromator. The output light from the monochromator is used for absorption spectroscopy. 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%. For the resolution the interference effect due to the use of the multibunch beam is negligible. A part of the output light from the monochromator is reflected by a splitter to a detector. This system for compensating the change in the light intensity works effectively when the electron beam is focused on the Al plate.

The stability of the light intensity for 25 minutes has been investigated at a wavelength of 985 μm, where the peak intensity of the output signal of the detector has been averaged over 30 pulses. The fluctuation of the intensity after the compensation with the splitter system has been ±2.3%.

In the absorption spectroscopy for liquid water, the peak value of the pulsed signal of the detector averaged over 20 pulses is measured. For each wavelength five measurements are performed. Distilled and then deaerated water is used as a sample. The sample and spacers to fix the thickness of the sample are sandwiched with two plates of anhydrous quartz 3 mm thick. The thickness of the sample is 0.186±0.003 mm. This sample holder is installed in a copper block, in which the temperature of the sample can be controlled.

4. Results and discussion

The intensity of the transmitted light has been measured for the sample with the holder plates and for a holder plate. The former result is shown in Fig. 2. The periodic oscillation observed on the spectrum is due to the interference of light in the sample and the holder plates. The behavior of the incident light in the sample and the holder plates is schematically shown in Fig. 3. The light is reflected at the surfaces 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 considering the behavior of light shown in Fig. 3 and by using the Kramers-Kronig relation [9], as shown in Fig. 4. The error in the data is ±2.8%. These well agree with the data previously obtained [7,8,10] while the wavelength resolution is much higher in the present experiment.

In this work a new system for the absorption spectroscopy has been established. This system is

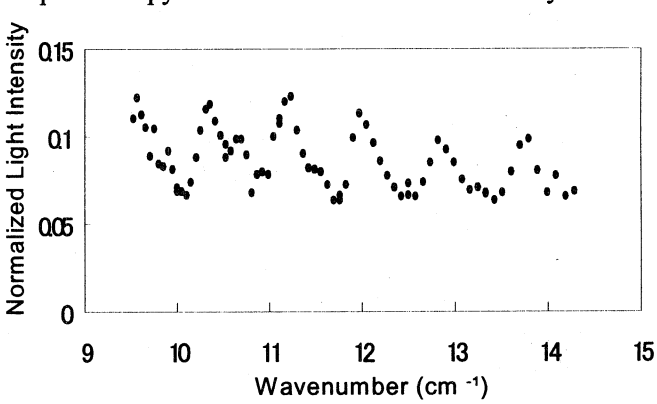

Fig. 2 The intensity of the light transmitted through the water sample with the holder plates, normalized by that of the incident light: the thickness of the sample is 0.186 mm and the temperature is 22 ℃.

being utilized for absorption spectroscopy for liquid water in the wider wavelength range changing the temperature of the sample. Imaging experiments at a certain wavelength and pulse radiolysis experiments using the pulsed coherent radiation and the single-bunch electron beam [2,11] are under preparation.

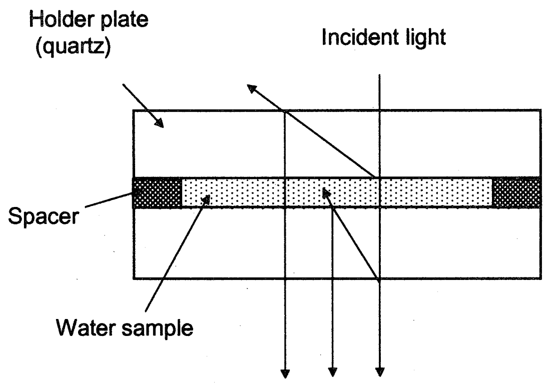

Fig. 3 Schematic diagram showing the behavior of the incident light in the sample and the holder plates.

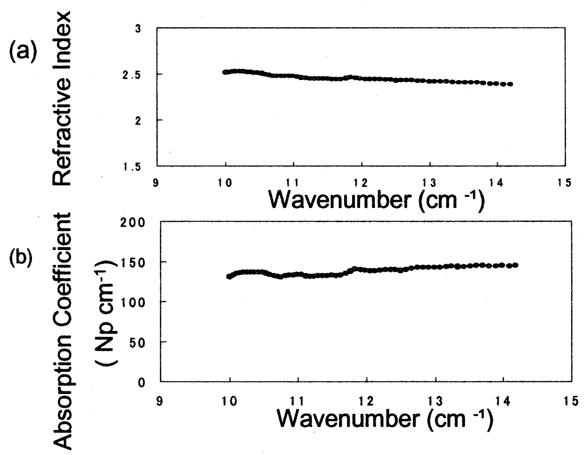

Fig. 4 The refractive index (a) and the absorption coefficient (b) of liquid water at a temperature of 22 ℃ obtained from the results for the measurement.

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 at ISIR. The output light from a grating monochromator was used for the spectroscopy for liquid water at a temperature of 22 ℃. 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.

Acknowledgements

This work was supported in part by a Grant-In-Aid for Scientific Research from the Ministry of Education, Science, Sports and Culture of Japan.

References

[1] T. Takahashi, T. Matsuyama, K. Kobayashi, Y. Fujita, Y. Shibata, K. Ishi, M. Ikezawa, Rev. Sci. Instr. 69 (1998) 3770.
[2] S. Okuda, M. Nakamura, K. Yokoyama, R. Kato, T. Takahashi, Nucl. Instr. and Meth. A 445 (2000) 267.
[3] S. Okuda, Y. Honda, N. Kimura, J. Ohkuma, T. Yamamoto, S. Suemine, T. Okada, S. Takeda, K. Tsumori, T. Hori, Nucl. Instr. and Meth. A358 (1995) 248.
[4] K. Yokoyama, Y. Miyauchi, S. Okuda, R. Kato, T. Takahashi, Proc. 20th Int. Free-Electron Laser Conf., Williamsburg, USA, 1998, II-17.
[5] S. Okuda, M. Nakamura, M. Takanaka, T. Kozawa, S. Nam, Proc. 23rd Int. Free-Electron Laser Conf., Darmstadt, Germany, 2001.
[6] J. T. Kindt, C. A. Schmuttenmaer, J. Phys. Chem. 100 (1996) 10373.
[7] D. S. Venables, C. A. Schmuttenmaer, J. Chem. Phys. 108 (1998) 4935.
[8] Y. Shibata, K. Ishi, T. Ohsaka, H. Mishiro, T. Takahashi, M.Torizuka, Nucl. Instr. and Meth. A301 (1991) 161.
[9] T. G. Goplen, D. G. Cameron, R. N. Jones, Applied Spectroscopy 34 (1980) 652.
[10] M. N. Afsar, J. B. Hasted, J. Opt. Soc. Am. 67 (1977) 90.
[11] T. Kozawa, Y. Mizutani, K. Yokoyama, S. Okuda, Y. Yoshida, S. Tagawa, Nucl. Instr. and Meth. A 429 (1999) 471.