PROJECT OF INFRARED STORAGE RING FREE ELECTRON LASERS AT AIST

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Abstract

Development of free electron lasers (FELs) with a compact storage ring NIJI-IV in the near and middle infrared regions is planned in National Institute of Advanced Industrial Science and Technology (AIST). Infrared FELs with a linear accelerator have been already developed and used for various applications in many FEL facilities. However, there is no storage ring FEL (SRFEL) which can oscillate in those regions widely. Although an SRFEL is inferior to a linear accelerator FEL in an average power, it has an extremely stable wavelength and its spectrum line width is as narrow as that of a monochromatic light in a synchrotron radiation facility. The optical klystron ETLOK-III for the infrared FEL has been already installed in the NIJI-IV, and the spontaneous emission from the ETLOK-III has been measured. New optical cavity chambers which could suppress low-frequency vibrations are designed. They will be installed in the NIJI-IV in February. An infrared SRFEL will be achieved by the end of this year.

INTRODUCTION

Oscillations of free electron lasers (FELs) have been developed with a compact storage ring NIJI-IV in National Institute of Advanced Industrial Science and Technology (AIST). The first lasing was achieved at wavelengths of 595 and 488 nm in 1992 [1]. Improvements of the electron-beam qualities in the NIJI-IV have been advanced for shortening FEL wavelength. The wavelength of 212 nm, at which an FEL oscillation was achieved with the NIJI-IV, was the record for the shortest wavelength of FELs in 1998 [2]. The wavelength of the NIJI-IV FEL was down to 198 nm in 2003 [3], and the NIJI-IV FEL reached to the VUV region. FELs in the deep UV and VUV regions are suitable as an intense light source to observe chemical reactions which are occurred on the surface of transition-metals because the work function of the transition-metals lays around 5 eV. Then, experiments of photoelectron emission microscopy with the NIJI-IV FELs have been developed, and catalytic CO oxidation on Palladium surface was observed with video-rate time resolution [4]. FEL experiments for further shortening the wavelength below 195 nm are being carried out.

A new challenge to enhance the region of the NIJI-IV FEL wavelength has been advanced. A new optical klystron ETLOK-III, which was designed for the infrared FEL oscillations in a wavelength region of 1-10 μm, was installed in a long straight section of the NIJI-IV in 2004 [5]. Although many infrared FEL facilities based on linear accelerators are operating, no SRFEL has been achieved in the wide infrared region. Generally, an SRFEL has the advantage of a narrow spectrum line width and stability of the lasing wavelength compare with a linear accelerator FEL. It can be used as well as synchrotron radiation passed a monochromator. The average power of the synchrotron radiation in an infrared beam line is about 10 μW at most. Then the SRFEL can be expected as a light source which is more intense than the synchrotron radiation. The output power which is our target is 1 mW. Spectra of spontaneous emission from the ETLOK-III have been already observed in the visible and near-infrared regions. New optical cavity chambers for adjusting positions and rotations of the cavity mirrors will be installed in the both ends of the long straight section in February. In this article, we explain the recent status of the development of the infrared SRFEL with the NIJI-IV.

INSERTION DEVICE

The insertion device for the infrared FEL oscillations, optical klystron ETLOK-III, has two 1.4 m undulator sections and a 72 cm dispersive section [6]. Figure 1 illustrates outline of the magnet arrangement of the ETLOK-III. Gap of the undulator section can be changed between 36 and 150 mm, and number of the periods in one undulator section is 7. The maximum K value is estimated to be 10.4 from the observed spontaneous emission spectra. Gap of the dispersive section can be changed between 42 and 188 mm. Because the magnets in the dispersive section are inserted between two tables which fix the magnets of the undulator sections, the gap of the dispersive section cannot be opened from the gap of the undulator sections over 38 mm. The dispersive section is so long that the electron beam with comparatively low energy meanders greatly in it. The electron beam passes in magnetic field of the dispersive section which is not uniform in the horizontal direction. Then the electron beam is kicked in the dispersive section and comes off the central axis of the ETLOK-III. The kick force becomes stronger as the gap of the dispersive section becomes smaller. The minimum dispersive gap at which the electron beam could be stored in the NIJI-IV was 80 mm. To cancel the kick force, we attached 5 mm iron plates to shunt magnetic field of the both end magnets in the dispersive section with a couple of 3 mm

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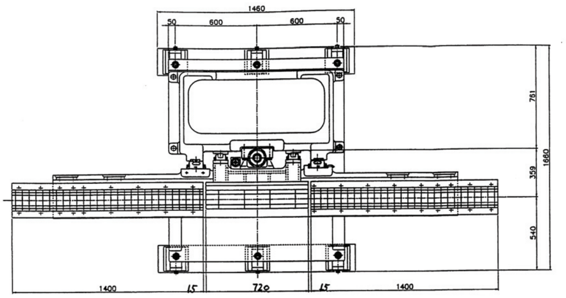

Figure 1: Schematic view of the optical klystron ETLOK-III.

thickness coils. The plate can be shifted on the side of the end magnet in the dispersive section. We will investigate the effect of the plates on the electron-beam trajectory soon.

OBSERVED SPONTANEOUS EMISSIONS

Spectra of the spontaneous emission from the ETLOK-III were measured with a photodiode array attached to a monochromator [5]. The resolution of this measurement system was estimated to be about 0.2 nm. Because the dispersive section has a parabolic distribution of magnetic field in the horizontal direction, precise adjustment of the electron-beam orbit is necessary to obtain a large modulation factor for the spontaneous emission. Figure 2 shows a spectrum of spontaneous emission with the undulator gap of 140 mm and the dispersive gap of 170 mm. The resonant wavelength measured in this condition was about 480 nm, and it was agreement with the wavelength estimated from the measurement of magnetic field in the ETLOK-III. The energy spread of the electron bunch can be estimated from the modulation factor of the spontaneous emission spectrum [7]. Taking the resolution of the measurement system into consideration, the energy spread was evaluated to be 2.7×10^{-4} in the undulator gap of 140 mm. This value was good agreement with the natural energy spread of 2.6×10^{-4}.

We could observe spectra of the higher harmonic emission in the UV and the visible regions. Figure 3 shows a spectrum of the third harmonic emission with the undulator gap of 100 mm and the dispersive gap of 130 mm. The resonant wavelength measured in this condition was about 1.42μm, so that it was about 2.2% longer than the wavelength estimated from the measurement of magnetic field in the ETLOK-III. The energy spread evaluated from the spontaneous emission was about 3.1×10^{-4}. Generally, further precise adjustment of the electron-beam orbit is demanded for the higher harmonics. The overestimation for the energy spread would be caused by the misalignment of the electron-beam orbit and/or the kick force in the dispersive section.

The maximum FEL gain is estimated to be over 2% at the electron-beam current of 15 mA in the visible and near-infrared regions. The maximum FEL gain for the third harmonics would be over 6% in the visible region due to rather large N_d, which is a number of periods of the FEL wavelength passing over an electron in the dispersive section. Because high-reflection mirrors of 99.8% or more are available in those regions [5], it will be easy to realize FEL oscillations after installation of optical cavity chambers in the both ends of the long straight section.

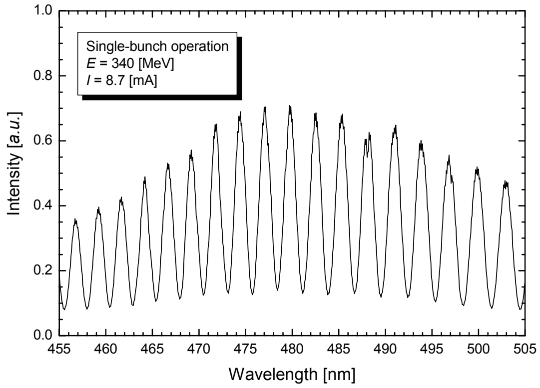

Figure 2: Spectrum of the fundamental emission from the TLOK-III with g_u (undulator gap) = 140 and g_d (dispersive gap) = 170 mm.

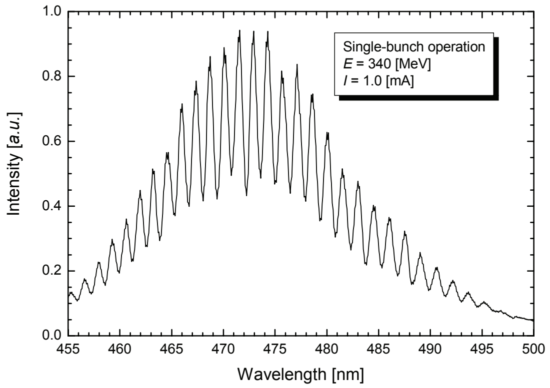

Figure 3: Spectrum of the third harmonics emission from the ETLOK-III with g_u = 100 and g_d = 130 mm.

DESIGN OF OPTICAL CAVITY CHAMBER

Stable optical cavity chambers in which cavity mirrors are mounted are necessary to obtain stable cw oscillations in the SRFELs. When longitudinal overlapping between an electron beam and an optical pulse are insufficient, micropulses of the SRFELs form macro-temporal pulses, and cause unstable cw lasing. Not only the intensity of the SRFELs but also the pulse width and the spectral line width are unstable [8]. When the longitudinal overlapping is almost perfect, a cw lasing with the extremely steady line width was observed with the ETLOK-II in the UV NIJI-IV FEL as shown Fig. 4. A threshold detuning length where the steady cw lasing appears depends on the effective FEL gain. In the case that the FEL gain is larger enough than the cavity loss, the threshold detuning length is about 0.5 μm for the UV NIJI-IV FEL. Then, it is

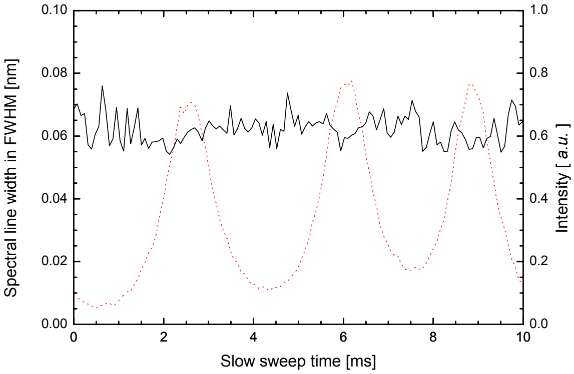

Figure 4: Evolution of the spectral line width of the SRFEL micropulse measured at the electron-beam current of 19 mA and the wavelength of 300 nm in the nearly perfect longitudinal overlapping. The micropulse intensity is also shown in the dotted line for comparison.

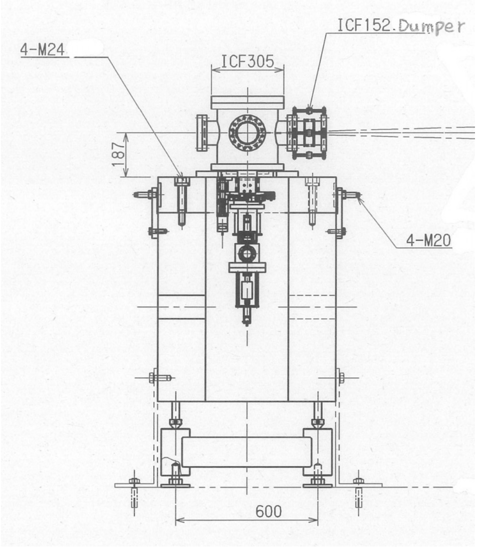

Figure 5: Overview of the new optical cavity chamber.

necessary to suppress amplitude of vibrations on the new optical cavity chambers for the infrared FELs within 0.5μm.

In order to estimate the vibrations on the optical cavity chambers, we measured vibration spectra with an accelerometer (Akashi AVT103) where the optical cavity chambers will be set up. Generally vibrations in the low frequency have large amplitude. There were some peaks around the frequency of 3 Hz in the vibration spectrum, and the maximum amplitude in those peaks was about 0.4 μm. Then, we adopted granite with the weight of about 1 ton as a stand to suppress the low-frequency vibrations. A vibration dumper which was able to intercept the low-frequency vibrations from the storage ring NIJI-IV was installed between the bending magnet chamber and the optical cavity chamber. Overview of the optical cavity chamber is illustrated in Fig. 5. The amplitude of vibrations at the cavity mirror will be controlled within 0.5 μm by these devices.

An optical cavity mirror holder, which is installed in the optical cavity chamber, can be controlled by stepping motors for three-axis positioning and two-tilt angles perpendicular to the optical axis. The nominal resolutions for the position on the optical axis and the tilt angles are 0.1 μm and 5 μrad, respectively. The mirror hold contains two remotely inter-changeable mirrors of up to 51 mm diameter. Effective diameter of the cavity mirror is 46 mm, so that a diffraction loss at the cavity mirrors will be negligible small in a wavelength region below 10 μm. The new optical mirror chambers for the infrared FEL will be installed in the NIJI-IV FEL system in February.

CONCLUSIONS

An active project to develop the first storage ring FEL in the near and middle infrared regions has been described. The optical klystron ETLOK-III was installed in the storage ring NIJI-IV for infrared FEL oscillations. The spectra of the spontaneous emission from the ETLOK-III were measured in the visible and the near-infrared regions. It was expected that the maximum FEL gain in those regions was over 2%. In order to obtain stable cw lasing, new optical cavity chambers for the infrared SRFEL were designed. The optical mirror holder can be precisely controlled by stepping motors for three-axis positioning and two-tilt angles perpendicular to the optical axis. The mirror chambers will be installed in the NIJI-IV FEL system in February. The first lasing with this system in the infrared region will be achieved by the end of this year.

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