LASING OF NEAR INFRARED FEL WITH THE BURST-MODE BEAM AT LEBRA

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Abstract

Improvement of the electron beam injector system in the linac at the Laboratory for Electron Beam Research and Application (LEBRA) of Nihon University made possible to accelerate the burst-mode beam extracted from the conventional DC triode electron gun. The electron beam with the pulse width less than 1ns and the period of 44.8ns, which corresponds to the round-trip time in the FEL optical resonator, has been extracted by using a high-speed grid pulser (Kentech Inc.). Taking into account of the electron beam pulse width, sequence of two or three FEL pulses with the accelerating RF period was possible. In the lasing experiment a single FEL pulse or a row of two FEL pulses was observed using a streak camera. By the adjustment of the timing of the high-speed grid pulse generated in synchronism with the accelerating RF, lasing of a single FEL pulse in the single short beam pulse has been observed at an FEL wavelength of approximately 1800nm. The result suggests that a single FEL pulse with 44.8ns period is available in the wavelength range from 1600 to 6000nm at the LEBRA FEL system.

LEBRA 125MEV LINAC

The LEBRA has supplied the infrared free electron laser and parametric X-ray (PXR) for various user experiments since 2004[1]. Table 1 lists the parameters of the linac in LEBRA. The linac uses the conventional 100kV DC electron triode gun. The emitted electron beam is accelerated to maximum 125MeV in three 4m accelerator tubes. Two klystrons (Mitsubishi Electric PV-3040) amplify to approximately 20MW and the amplified RF is fed to the prebuncher, buncher and accelerator tubes. The acceleration frequency is 2856MHz. Therefore, the electron beam is bunched in 350ps intervals.

Table 1: Main Parameter of the LEBRA 125MeV Linac

Accelerating RF frequency	2856 MHz
Klystron peak output power	30 MW
Number of klystrons	2
Electron energy	30 - 125 MeV
Energy spread	0.5 - 1 % FWHM
Macro pulse beam current	200 mA
Macro pulse duration	20 μsec
Repetition Rate	12.5 Hz

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The accelerated beam is transported to the FEL undulator line by two 45-degree bending magnets. Table 2 lists the specification of the undulator. The length of the FEL optical resonator is 6720mm and the round trip time is 44.8ns.

Table 2: LEBRA Undurator Parameter

Resonator length	6720 mm
Undurator length	2.4 m
Undurator period	48 mm
Number of periods	50
Maximum K Value	1.35 rms

ELECTRON GUN IMPROVEMENT

Upgrading of the control system for the conventional DC electron gun was completed on January 2011. A high speed grid pulser was added in the upgrade. Figure 1 shows schematic diagram of the updated electron gun system.

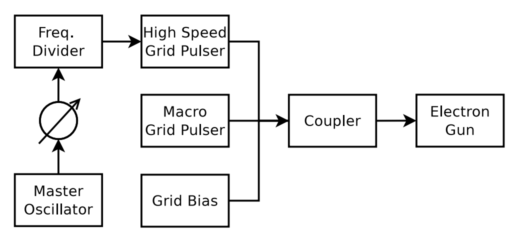

Figure 1: Schematic diagram of the electron gun system.

The RF generated from the master oscillator is fed to the frequency divider. The high-speed grid pulser is driven by the 89.25MHz sine wave output from the frequency divider as a master clock input. The clock input is divided internally by 2 or 4. The gated output of the pulser is a train of short pulses with a period of 22.4ns or 44.8ns and a pulse width of 600ps FWHM. The output of the high-speed grid pulser is superimposed on the output of the macro grid pulser by the grid pulse coupler, and fed to the grid of the electron gun. Thus, there are 3 beam modes, full bunch mode, burst mode and superimpose mode as illustrated in Fig. 2. The beam mode becomes "full bunch mode" when the macro grid pulser is turned on and the high-speed grid pulser is turned off. In this mode, the maximum macropulse width of the accelerated beam is 20μs and the interval between the bunches is 350ps.

When both of the grid pulsers are active and the output voltage of the macro grid pulser is higher than the threshold

ISBN 978-3-95450-117-5

of the electron emission, the beam mode becomes "superimposed mode". When both of the grid pulsers are turned on but the output voltage of the macro grid pulser is lower than the the electron emission threshold, the beam mode becomes "burst mode". In this mode, the electron beam with a pulse width of 600ps is emitted at an interval of 22.4ns or 44.8ns. Figure 3 shows two typical states in the timing between the high speed grid pulse and the beam bunches formed in the linac by the burst mode emission. It is suggested that a single bunch beam can be accelerated in each emission of the burst beam by adjusting the grid bias voltage and the timing of the high speed grid pulse relative to the accelerating RF phase.

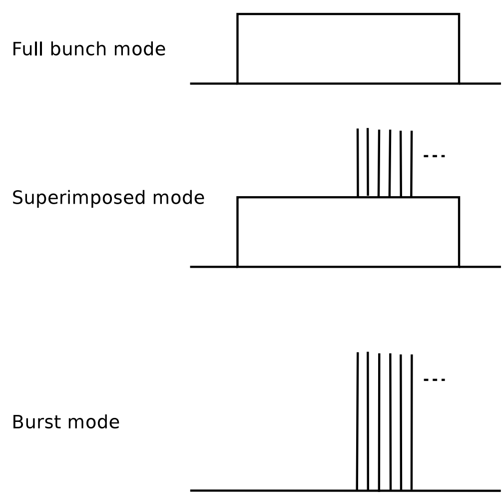

Figure 2: Typical states in the timing between the high speed grid pulse and the beam bunches formed in the linac by the burst mode emission.

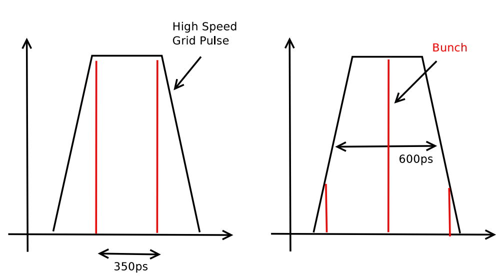

Figure 3: Three typical beam modes obtained with the upgraded gun system.

FEL LASING WITH THE BURST-MODE BEAM

On April 19th, 2011, it is succeeded in lasing FEL with burst mode. The operator lased FEL first and decreased the macro pulse voltage while adjusting the machine to maintain lasing.

When the grid bias voltage was 53V and the macro grid pulse voltage was less than 35V, the accelerated beam becames only burst beam, and the FEL was keeping lasing.

The wavelength of the FEL was approximately 1800nm, FEL power was approximatery 2.3mJ per macropulse and burst pulse period was 44.4ns, at that time. Figure 4 shows the faraday cup output voltage and the InSb infrared detector output voltage. In this figure, the horizontal axis expresses time and vertical axis expresses output voltage from the faraday cup and InSb infrared detector.

On April 19th, 2011, the first lasing of the burst mode FEL was achieved by the following process. At first the gun was operated with the full bunch mode. Once the lasing at the full bunch mode was obtained, the high speed grid pulser was turned on. After adjustment in the linac operating condition the lasing was regained, then the macro grid pulse voltage was gradually decreased while adjusting the linac to keep lasing. Eventually at a sufficiently low macro grid pulse voltage as compared to the threshold of the macropulse emission, the FEL lasing was still observed at the burst mode beam acceleration. At the grid bias voltage of 53V and the macro grid pulse voltage lower than 35V, the beam was accelerated effectively in the burst mode. In the experiment the FEL power obtained at the monitoring port was approximately 2.3mJ per macro pulse with a wavelength of approximately 1800nm and a burst pulse period of 44.8ns.

Figure 4 shows the beam current waveform obtained at the Faraday cup and the FEL intensity waveform measured at the FEL monitoring port using an InSb infrared detector. In the figure, the horizontal axis shows the time in micro sec and the vertical axes show the output voltage from the corresponding detectors. The FEL lasing achieved saturation and its duration was approximately 10μs.

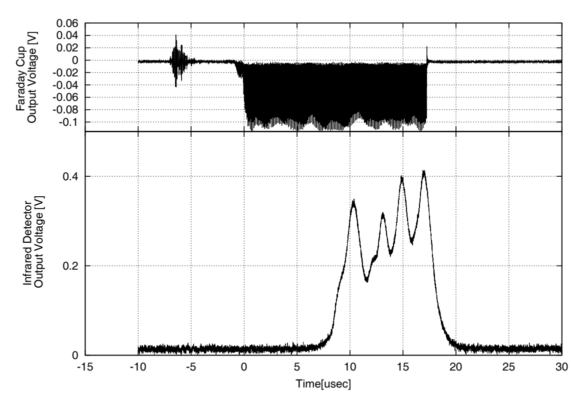

Figure 4: The faraday cup output voltage (upper) and the InSb infrared detector output voltage (lower).

FEL PULSE STRACTURE

The pulse structure of the 3rd harmonic of the FEL in each mode was measured using a streak camera. The streak camera (HAMAMATSU C979) is sensitive in the wavelength region from 400 to 800nm, with the maximum resolution of 10ps. In this experiment the wavelength of the

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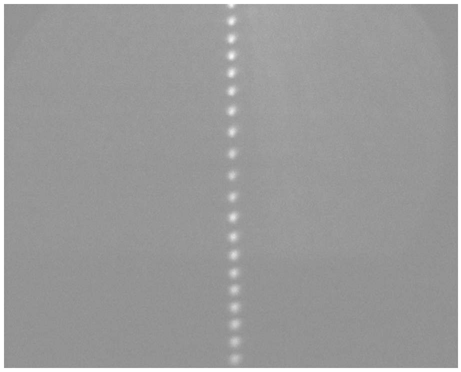
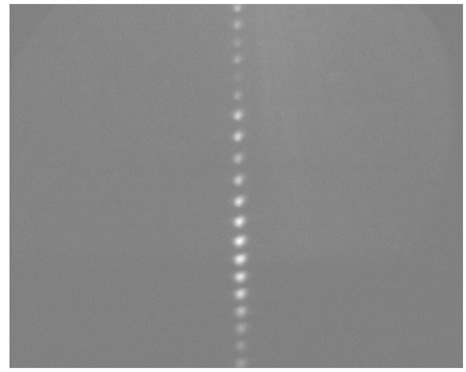
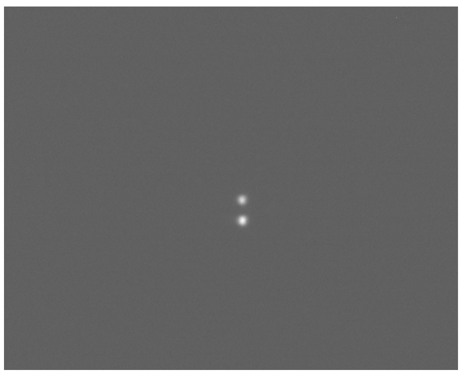


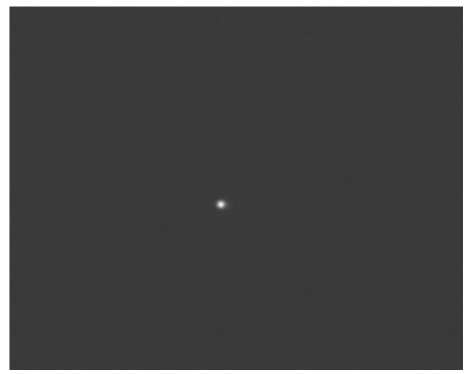
(a) Full bunch mode



(b) Superimposed mode



(c) Burst mode (double bunches)



(d) Burst mode (single bunch)

Figure 5: Images of the FEL pulse structure observed using a streak camera for different beam modes.

FEL was set to 2160nm, and the 3rd harmonic 720nm photons were detected at the streak camera.

Figure 5(a) shows the streak image of the FEL pulses in the full bunch mode. A series of the optical pulses with a uniform intensity in 350ps intervals is seen running in the vertical direction. When the high speed grid pulse was superimposed the intensity of the optical pulse was modulated as shown in Fig. 5(b). The modulation of the FEL pulse intensity became more significant by lowering the macro grid pulse voltage, and the beam mode eventually became the burst mode when a row of two optical pulses remained as shown in Fig. 5(c).

The number of the optical pulses in the burst mode beam was reduced to one by adjusting the timing of the high speed grid pulse using the phase shifter before the frequency divider, which is shown in Fig. 5(d). This suggests that the burst mode beam was accelerated approximately in the timing as illustrated in Fig. 3(b), where only a single beam bunch contributed to intense lasing and possible acceleration of satellite bunches seemed to have negligibly small effects.

PULSE LENGTH MEASUREMENT

Since the FEL pulse is a coherent wave packet, the approximate pulse length can be deduced from autocorrelation measurements. The shape of the autocorrelation trace in each beam acceleration mode was measured at a wavelength of 1600nm with a Michelson interferometer [2]. Figure 6 shows the measured autocorrelation trace. In the figure the horizontal axis shows the position of the movable mirror in the interferometer, and the vertical axis shows the relative intensity of the FEL detected with an InGaAs photo diode. Figure 7 shows the FEL pulse length as a function of the macro grid pulse voltage for each beam mode. In the superimposed mode, the FEL pulse length seems to be longer in the lower macro grid pulse voltage region.

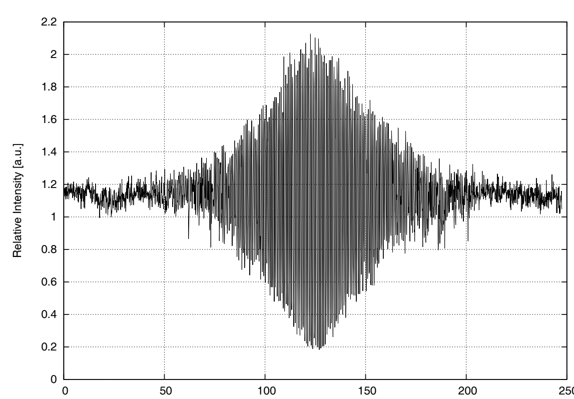


Figure 6: The autocorrelation trace in burst mode FEL lasing.

ISBN 978-3-95450-117-5

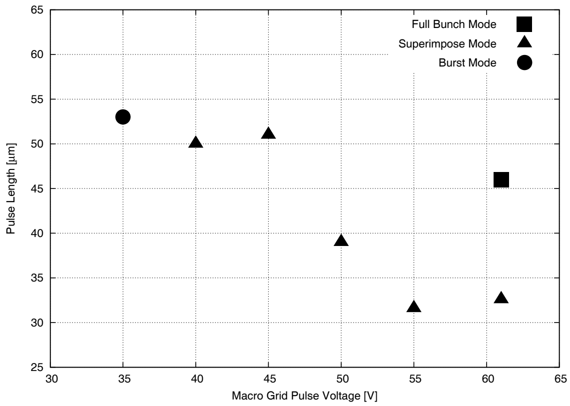


Figure 7: The correlation between macro grid pulse voltage and FEL pulse length.

CONCLUSION

The high-speed grid pulser was introduced in the electron gun system of the LEBRA linac. Extraction of the superimposed mode beam and the burst mode beam were carried out, and FEL was successfully lased in these modes.

Lasing of a single or double FEL pulses in a single burst beam pulse was observed using the streak camera, which was controlled by the timing adjustment of the high speed grid pulse.

The result suggests that a single FEL pulse with 44.8ns period is available in the wavelength range from 1600 to 6000nm at the LEBRA FEL system.

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ISBN 978-3-95450-117-5