First lasing of the CLIO FEL

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Abstract

Laser oscillation between 5 and 10 µm has been obtained with CLIO ("Collaboration for an Infrared Laser at Orsay"). An S-band FEL dedicated linac has been built for this purpose. The electron beam energy was 40 MeV in this set of experiments. A 0.5 nC charge per bunch of 15 ps duration was passed through a 2 m long undulator. The resonator is a 4.8 m long, metal mirror, optical cavity. The optical beam was coupled out by a CaF_2 or ZnSe plate near Brewster incidence (60°). The first measurements of the accelerator and laser characteristics are presented.

1. INTRODUCTION

The CLIO collaboration was started in 1987 [1] in order to build an infrared laser at LURE, Orsay. This goal has been achieved on 17th January 1992, when a first laser beam of 5 µm wavelength was obtained. The project had the benefit of both the experience of the LURE team in the FEL field, and of the LAL laboratory in the design of 3 GHz RF linear accelerators.

CLIO is a user dedicated machine, but fundamental FEL experiments will also be performed. According to the first results described hereafter, the expected main characteristics of the laser beam are summarised in table 1.

Table 1
Main FEL features

Spectral range	2-20 µm
Max. average power	20 W
Peak power (macropulse)	6 - 50 kW (8 µs)
Peak power (micropulse)	15 MW (10 ps)
Energy / macropulse	40 - 300 mJ
Repetition rate:	
macropulse	1 - 50 Hz
micropulse	every 4 - 32 ns

The general synoptic of the machine is shown in fig. 1. The main components of the accelerator and the optical cavity are described in the following sections.

2. THE CLIO MACHINE

2..1. Accelerator

The linac consists of a 100 kV thermionic triode gun, a 500 MHz subharmonic buncher, a 3 GHz fundamental frequency buncher (standing wave), and a 3 GHz travelling wave accelerating section.

The gun operates in a pulsed mode: it emits short pulses every 4, 8, 16 or 32 ns (optical cavity round-trip time) during an 11 µs long macropulse. This 11 µs duration corresponds to the flat-top length of a 12 µs klystron pulse. The electron bunches have a gaussian-like temporal distribution, 2 ns long at the base and nearly 1 ns at half-width. Each of them carries a 1 nC charge.

The subharmonic buncher phase compresses the bunches by velocity modulation, allowing them to reach the fundamental buncher (FB) within it's phase acceptance ($\delta\phi = 0.2$ ns). The FB in turn compresses them to 10-15 ps FWHM, while accelerating them to 4 MeV (or 3 MeV if beam-loading arises, due to high average current). Then the TW section accelerates them to their final energy, between 30 and 70 MeV. In our set of experiments, current was low (one micropulse every 32 ns, macropulse repetition rate of 6.25 Hz), and final energy fixed at E = 40 MeV. Both experiments and PARMELA simulations indicate the bunching process produces a 65% current transmission at the exit of the FB with a micropulse length in the 10-15 ps range [2]. The emittance at the same location was estimated by PARMELA to be 40π mm mrad (90% particles, normalized). A maximum value of 60π mm mrad was experimentally obtained in July 1991 by using two slits located after the accelerating section and 3 m apart. A second measurement yielding 80π mm mrad was made at the entrance of the undulator in December 1991, using a glass plate irradiation method. Within the limits of experimental error, the agreement between these two set of measurements is very satisfactory.

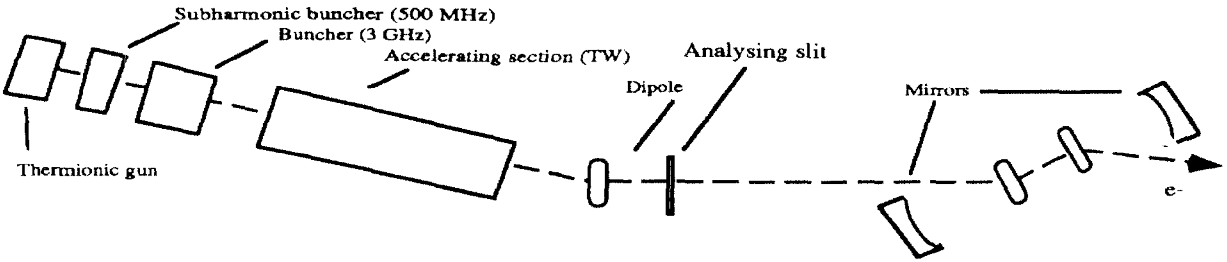

Fig. 1. Synoptic of the CLIO experiment.

Table 2
Main accelerator features

Type	3 GHz rf linac
Energy range	50 ± 20 MeV
Electron gun	gridded thermionic dispenser cathode
Subharmonic buncher freq.	500 MHz
Fundamental buncher type	standing wave
Accelerating section type	travelling wave (4.5 m)
Klystron	TH 2130 V
Micropulse length (FWHM)	10-15 ps
Macropulse length (flat-top)	11 μs
Micropulse peak current (estimated)	50 A
Micropulse charge	
at gun exit	1 nC
at undulator entrance	0.5 nC
Micropulse interval	4, 8, 16, 32 ns
Macropulse repetition rate	6.25, 12.5, 25, 50 Hz
Average beam power	up to 7.5 kW
Emittance: $4\pi\beta\gamma\sigma\sigma'$	
required	< 150π mm mrad
calculated	40π mm mrad
measured	80π mm mrad
Measured energy spread (FWHM)	0.7 %

The measured characteristics and other main features of the accelerator are summarised in table 2. Measured characteristics refer to experimental conditions described previously.

Among minor problems to be solved on the accelerator is a remaining linear phase shift of the microbunches of 5° (3 Ghz) at the entrance of the undulator. This should decrease the laser quality, because it corresponds to a temporal shift of 5 ps, not negligible relative to the 10-15 ps duration of the light micropulse. It is also planned to measure the micropulse length (by dephasing the accelerating section/buncher and measuring the induced dispersion) in order to obtain a better estimate of the peak current and of the overall stability.

2.2 Optical cavity and undulator

The optical cavity, defined by two metallic mirrors, is 4.8 m long. It includes a 2 m long undulator [3], some magnetic devices for electron beam guiding and focusing, beam position and profile monitors, and an extraction device. The main features of the undulator are summarised in table 3.

At the present time, the optical beam is coupled out by a CaF_2 or ZnSe plate near Brewster incidence (60°). CaF_2 and ZnSe extract respectively 0.8 % and 5.0 % of the power in the cavity. CaF_2 has been used to minimize the losses in order to obtain the laser for the first time and to lase on the third harmonic, and ZnSe to optimize the power coupled out.

Table 3
Main features of the undulator

Length	0.96 m + 0.96 m (tapered)
Period	4 cm
Number of periods	2 x 24
Gap	adjustable > 11.7 mm
K	0 - 2

3. FIRST RESULTS

3.1. Lasing on the fundamental

Lasing at wavelengths between 5 and 10 μm has been achieved on the fundamental since January. Changing the wavelengths requires modification of the cavity length according to dn/dλ in the extracting plate so that the wavelength cannot be swept continuously yet. This will be done in the near future by changing automatically the cavity length and/or by using hole coupling. Saturation and measurable power have been obtained in all cases. Table 4 summarises the most significant results.

Table 4
Measured laser characteristics.

Spectral range (1st harmonic)	5 - 10 μm
Gain at 5 μm	
measured	25 %
theory for I=50 A	40 %
Gain at 8 μm	
measured	70 %
theory for I=50 A	75 %
Extracted power:	
peak (micropulse)	6 MW
average (macropulse)	2 kW
time average	100 mW
Efficiency	
measured	0.3 - 0.4 %
theoretical	0.5 %

Reported gain values are net. They are estimated from the laser risetime at the very beginning of the laser growth to which the losses, estimated from the decay time, are added.

The following figure shows an example of observed saturation.

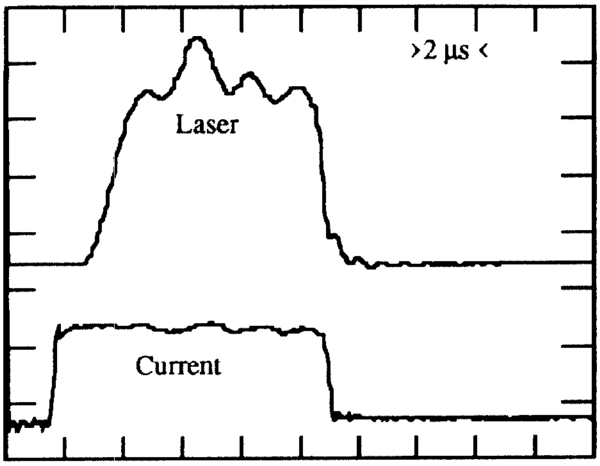

Fig. 2. Laser saturation at 8 μm; ZnSe plate.

With the ZnSe plate, total losses are estimated to be 7% (by assuming 2 % losses on the mirrors). This is in agreement with the measured value of 8 %.

This corresponds to good experimental conditions, with saturation achieved in 2-3 μs, and a 8 μs steady state. By extrapolating these results to the maximum rate (for which administration authorization is awaited), we should obtain 6.4 W of average produced power, and 16 kW per macropulse, corresponding to 130 mJ in a macropulse. By using a tapered undulator configuration, we should gain a factor 2 to 3 on these values, thus reaching the specifications of table 1.

3.2. Harmonics

Coherent harmonics have been detected up to eighteenth order (at 1.27 μm) for a fundamental wavelength of 10.1 μm, using the ZnSe Brewster extracting plate with E=40 MeV and K=2.

Lasing on the third harmonic has been achieved at 3.3 μm in the same conditions but with CaF_2 rather than ZnSe, as shown in fig. 3. The net gain was measured to be 12-15 %, to be compared to 22 % theoretically. However, this gain is too small to reach a level where a significant amount of power could be extracted. It is planned to lase at this wavelength on the first harmonic at 50 MeV.

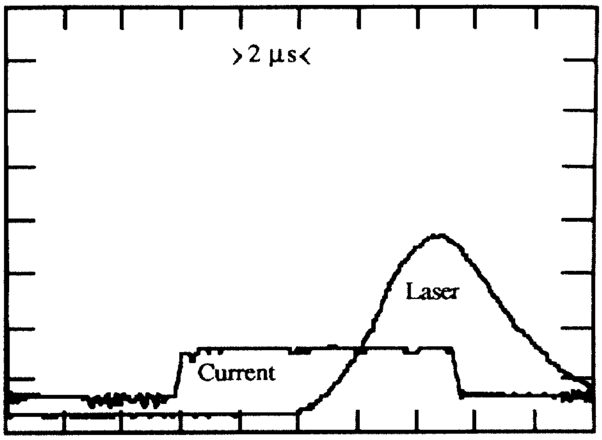

Fig. 3. Laser on third harmonic (3.3 μm)

4. CONCLUSION AND PERSPECTIVES

These first results of CLIO will be improved and extended in the next few months, but are already good enough to consider the first applications. The next stages of development will include:

- Extending the spectral range, by running the linac at 30 and 50 MeV. The 3-15 μm domain should not cause any problem. Below 3μm, some problems of klystron power breakdown may arise. For λ>15 μm, trouble may come from optical materials or machine adjustment at low energy.
- Systematic studies of laser properties (power, spectral width, stability) versus optical cavity length.
- Study of optical beam outcoupling by a hole in a mirror.
- Installation of the optic line for users.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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