Initial Optical Measurements on the IR Demo*

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Abstract

The initial measurements from lasing of the IR Demo laser are presented. Early operation was around 5 microns. Both pulsed and CW operation were achieved. Spectra at various detunings and outcouplings are shown. Up to 311 Watts of CW power was produced.

1. Introduction

The IR Demo laser was operated with an electron energy of 38 MeV and 60 pC of charge per bunch. For other parameters see ref [1]. The electron bunch length was minimized using the coherent transition radiation from an aluminum foil, and estimated to be in the order of one picosecond FWHM [2].
The normal micropulse repetition frequency, for one optical pulse circulating in the laser cavity, is 18.7125 MHz. The cavity was surveyed during its assembly to be set at the synchronous length for this frequency to within 100 μm, and an adjustment by some 60 μm sufficed to obtain first lasing.
A mirror with 98% reflection was used as the outcoupler in the initial runs, to facilitate start-up of the laser. This outcoupler was later replaced by one with 90% reflection, for more output power.
To check the effect of larger outcoupling, or lower effective gain, the electron bunch repetition frequency was reduced by successive factors of two, so that the optical pulse experienced gain only in ½, ¼, etc., of its roundtrips.

2. Small outcoupling

In Fig. 1 we show the cavity detuning curve under standard conditions with the 98% reflective outcoupler. Lasing was insensitive to beam parameters and optical alignment. The width of the curve and the strongly increasing power near zero detuning also show that the laser operates far above threshold.
Some spectra of the output radiation are illustrated in Figs.2-4. In Fig.2, the cavity is shortened by 20

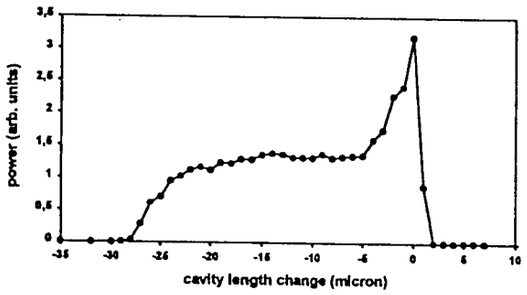

Fig. 1 Cavity detuning curve, 2% outcoupling

μm from its synchronous length, leading to a narrow spectrum. In this large detuning case, the optical pulse develops an exponential slope at its leading edge, with a length determined by the cavity loss and by the amount of detuning [3]. The observed full width at half maximum of about 4 nm for the main peak in Fig. 2 corresponds to a 3 ps 1/e-time for the pulse slope. This would indicate a cavity loss of about 4% rather than the 2.8% total mirror loss expected at this wavelength.

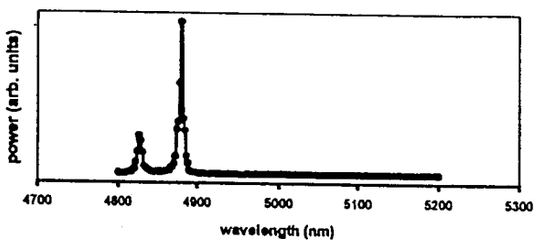

Fig. 2. Spectrum at 20 μm cavity detuning

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The origin of the smaller peak, shifted to shorter wavelengths by 53 nm, or 1.1%, is not yet explained.

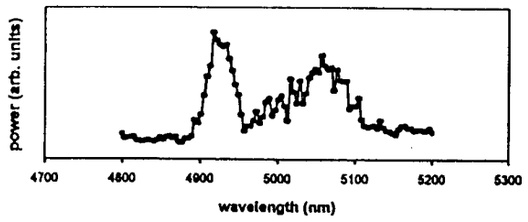

Fig. 3. Spectrum at 2 micron cavity detuning

A prominent sideband is seen in Fig. 3, at 2μm detuning. This indicates an intracavity power high enough to excite a sideband instability. At a slightly longer cavity length, as shown in Fig. 4, the measured spectrum suggests that the intracavity power has reached the regime of chaotic electron dynamics.

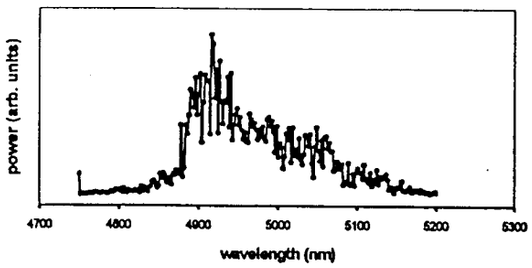

Fig. 4. Spectrum at near-zero cavity detuning

Lasing could still be maintained with a reduction of the electron bunch frequency by a factor of 8, which means that the gain is at least 25% per pass.
The results described so far were obtained with an electron beam consisting of macropulses of 200 μs duration, repeated at 2 Hz. Next, the laser was operated in the CW mode, and a stable output of 155 Watts was obtained.

3. Large outcoupling

In a second experimental run, an outcoupler with 90% nominal reflection was used. Again, detuning curves and spectra were measured for different micropulse repetition rates and also for a series of different bunch charges. The saturated output power at small detuning is reduced roughly by the same factor as the average current in both cases. The appearance of the detuning curves is different, however, because the effective detuning increases when the optical pulse has to make more roundtrips before meeting an electron bunch again.
An example of the spectrum at small detuning, under otherwise standard conditions, is shown in Fig. 5. The fine-structure is due to absorption by atmospheric water vapor. The presence of the sideband at the long wavelength side shows that the regime of nonlinear saturation is still reached with the outcoupling of 11% at this particular wavelength. While the output power is increased, the intracavity power is lower than in the small-outcoupling case, which reduces the load on the cavity mirrors.
In CW operation, an output power of 311 Watts was achieved with the nominally 10% outcoupling mirror.

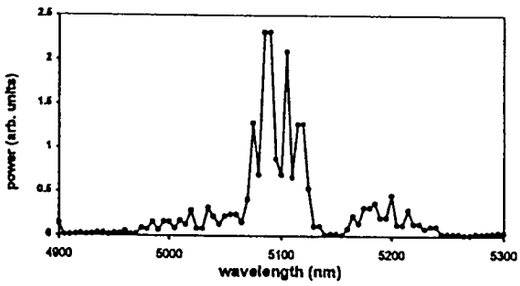

Fig.5. Spectrum at 1 micron cavity detuning, 11% outcoupling

4. Conclusion

The first measurements on the laser output show that the IR Demo basically lases as expected, although some details merit further study.

References

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[3] W.B. Colson, in: *Laser Handbook,* Vol 6, W.B. Colson, C. Pellegrini, and A. Renieri, Eds, North-Holland, Amsterdam 1990, p.179.