FAR INFRA-RED SUPER-RADIANT LASER ACTION IN METHYL FLUORIDE

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Abstract

Submillimetre laser pulses exceeding 1 MW power have been generated super-radiantly in CH_3F gas pumped by 200 MW of 9.55 micron CO_2 TEA laser radiation. When FIR output was restricted to operation on the 496 μm line alone, 0.5 MW was achieved within a bandwidth of 100 MHz.

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Attention has recently been drawn to the importance of powerful submillimetre lasers for plasma diagnostics, based on collective scattering of radiation by electron density fluctuations in plasmas of long Debye length[1,2,3]. Pulsed laser action in HCN at 337 microns at peak powers of 1 kW has been reported[4], and more recently, super-radiant laser action in CH_3F, pumped by the 8 joule output of a CO_2 TEA laser tuned to 9.55 microns has produced pulses of 30 kW peak power[5]. This letter presents the results obtained from a super-radiant CH_3F laser pumped by 200 MW CO_2 laser pulses.

The experimental assembly is illustrated in Figure 1. The double-discharge CO_2 TEA laser [6] consisted of two amplifying stages, preceded by an oscillator whose optical cavity was formed by an uncoated Ge flat and a 5 cm diameter gold-coated original diffraction grating having 150 lines mm^{-1} and blazed for 8 microns, giving a dispersion of 0.145 microns per degree. A typical CO_2 laser pulse consisted of a gain-switched 200 MW spike of about 60 nsec half-width followed by a tail lasting approximately 3 micro sec. The total energy was 65 J when the laser was operating on the 9.55 micron line.

The CO_2 laser radiation was directed axially down a 3.3 m length of 8 cm diameter glass pipe containing CH_3F gas. The pumping radiation entered the pipe through a KCl flat and the FIR output emerged through a TPX window[7] which was found to be totally opaque to 10 micron radiation. Pulses of FIR radiation were detected by a fast Si-W point-contact diode[8] and displayed on a 250 MHz bandwidth oscilloscope. A sample oscillogram appears in Figure 1.

The energy per unit area of output of the FIR pulses was measured using a calorimeter calibrated at the National Physical Laboratory, UK. The calorimeter was traversed along vertical and horizontal diameters of the output window, and approximately bell-shaped profiles, which were highly reproducible, were measured at a number of values of CH_3F pressure. Figure 2a shows the variation in total output energy as a function of CH_3F pressure. The maximum output, obtained at 3 torr, was 24 mJ, and this is more than an order of magnitude greater than previously published super-radiant energies[5]. The dependence of FIR energy on the CO_2 laser pump energy at 3 torr of CH_3F is shown in Figure 2b. The onset of saturation is apparent at the highest pump energy.

Although the TEA laser pumping pulse consists of a spike followed by a tail, it is the spike containing some 20% of the 65 J total energy, that drives the FIR super-radiant emission. The conversion efficiency achieved in the CH_3F is thus about 0.18%, which compares favourably with efficiencies reported elsewhere, but is substantially below the Manley-Rowe limit of 2%.

Comparison of these energy measurements with the FIR pulse shape gives a measure of the power. Pulse trains between 40 and 100 nsec long consisting of random spikes have been found with average power up to 400 kW and peak powers in excess of 1 MW.

Absolute wavelength and spectral bandwidth measurements of the FIR emission were carried out with a scanning Fabry-Perot interferometer equipped with copper mesh plates. The mesh was 10 wires mm^{-1} each way the wire diameter being 0.011 mm and the spacing width 0.089 mm. A Golay cell measured the radiation transmitted by the interferometer, and the complete system had an overall finesse of better than 13. Wavelength was measured, with a plate spacing of 1 cm corresponding to a free spectral range of 15 GHz, by traversing one plate and counting fringes.

At 2 torr the laser was found to operate equally strongly on both 452 micron and 496 micron lines. As pressure increases, the 452 micron line intensity diminishes until it has virtually vanished at 5 torr. The results are summarized in Figure 3 which displays the intensities of the two lines as functions of pressure, and shows that the peak output at 3 torr occurs with the laser operating on two about equally bright lines simultaneously. The peak intensity on the 496 micron line alone occurs at 5 torr when the total laser output is about half that measured at 3 torr. The pulse train displayed in Figure 1 was recorded at 5 torr.

The spectral bandwidth of the 496 micron line was measured by decreasing the free spectral range of the interferometer to 800 MHz. The Fabry-Perot fringes then showed evidence for microstructure within the 496 micron line, consisting of three closely spaced components, the central one being considerably more intense than its neighbours. The overall spectral width is about 300 MHz, but the width of the strong component alone is about 120 MHz. This width is the convolution of the true line width with the 55 MHz instrumental line.

The angular divergence of the 496 micron line at 5 torr was determined by focusing the beam with a 32 cm focal length TPX lens. The energy distribution in the focal spot was measured using the calorimeter with its sensitive area restricted to 0.25 cm^2, and was found to have a half-width of 22 mrad. 95% of the energy was confined within 30 mrads.

Super-radiant emission is expected to occur in both directions along the CH_3F tube. The fraction travelling back towards the CO_2 laser will be partly reflected on the KCl flat, and on its return journey up the tube, will be further amplified, contributing significantly to the output at the TPX window. That this is indeed the main contribution to the output is shown by the fact that when the KCl flat is mounted so that its normal is about 10^o to the tube axis, the FIR energy falls by a factor of about 5 times.

The FIR radiation was found to be plane polarized perpendicular to the direction of polarization of the pumping radiation, and this is consistent both with previous observations and with theoretical predictions(9).

In summary, a 13 J spike (65 J spike plus tail) of 9.55 micron CO_2 TEA laser radiation has been used to generate trains of super-radiant FIR pulses lasting up to 100 nsec, having energy of 24 mJ, and containing individual peaks reaching powers in excess of 1 MW. Spectral content of the FIR emission was found to depend on CH_3F gas pressure and maximum energy was obtained at 3 torr, when the output consisted of two equally bright lines, one at 452 microns and the other at 496 microns. At 5 torr, only the latter persisted and pulse energy and power were approximately half the maximum. The overall bandwidth of the 496 micron line was 300 MHz, made up of two weak components, plus one strong, the bandwidth of the latter being about 100 MHz. 95% of the FIR output was emitted within an angle of 30 mrad and it was polarized perpendicular to the plane of polarization of the pumping radiation.

With an order of magnitude improvement in performance this super-radiant laser could be employed to measure collectively scattered radiation from a 1 keV, 10^{13} or 10^{14} cm^{-3} plasma at a scattering angle of up to 30^{o}. Heterodyne detection using a narrow band local oscillator would of course be required.

References

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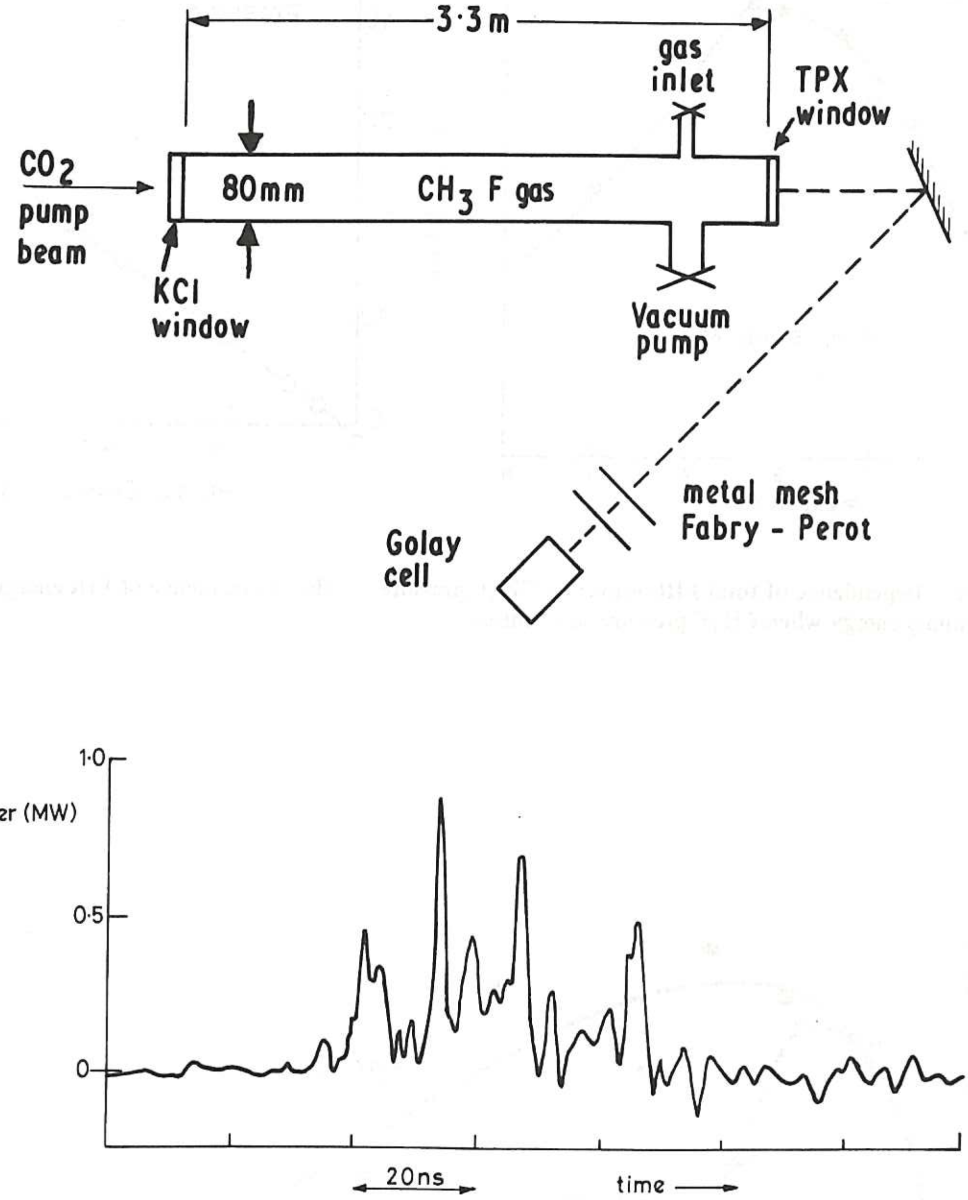

Fig.1 (a) Experimental assembly showing arrangement for measuring spectral content of super-radiant emission; (b) Oscillogram of FIR emission at 5 torr CH_3F pressure detected by Si-W point contact diode. 496 micron line alone.

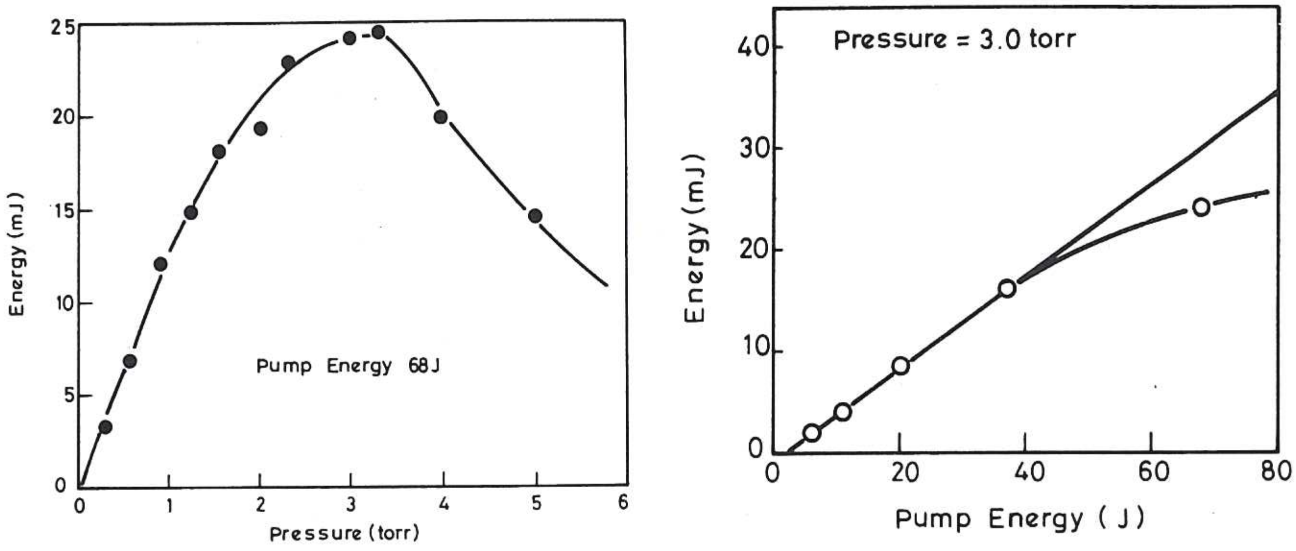

Fig.2 (a) Dependence of total FIR output on CH_3F pressure. (b) Dependence of FIR energy on 9.55 micron pump energy when CH_3F pressure was 3 mtorr.

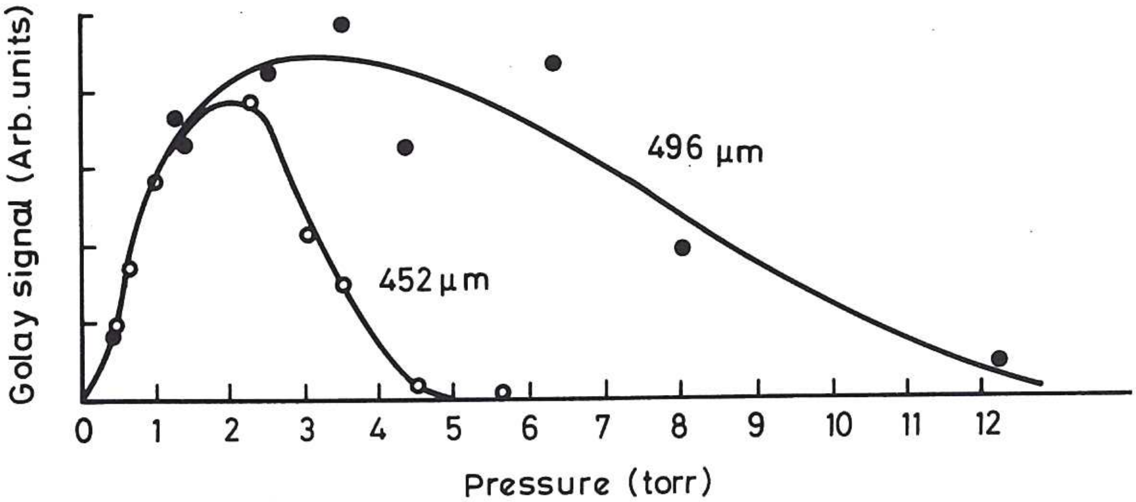

Fig.3 Energy in 452 micron and 496 micron lines as a function of CH_3F pressure with total pump energy 65 J.