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Abstract

Operation of a CH_3F laser at 496 microns has been obtained in a hemispherical optical cavity pumped by up to 42 J of 9.55 micron CO_2 TEA laser radiation. Highly modulated 1 microsecond pulses delivering 6 mJ at peak powers greater than 10 kW have been recorded.

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Submillimetre laser radiation has important applications in the diagnostics of plasmas of interest in controlled thermonuclear fusion research [1,2,3]. More than 1 MW of far infra-red (FIR) laser power has been generated superradiantly using the 9.55 micron line emitted by a CO_2 TEA laser to pump CH_3F in a 3 m glass pipe[4]. This power is shared amongst several spectral components and the elimination of all but one significantly reduces the output. An oscillator-amplifier assembly[5] is an alternative arrangement in which the high power narrow bandwidth pulse desirable for plasma diagnostic purposes could be produced, and a single mode transversely pumped oscillator delivering 500 W within 30 MHz at 496 microns has recently been reported[6]. The present letter gives an account of the operation of a CH_3F oscillator which emits pulses of more than an order of magnitude greater peak power distributed among 3 or 4 cavity modes.

The experimental layout is shown schematically in Figure 1. The CO_2 laser beam originated in a double-discharge TEA laser [7] consisting of two amplifier stages preceded by an oscillator formed between an uncoated Ge flat and a 5 cm diameter gold-coated original diffraction grating having 150 lines mm^{-1} and blazed for 8 microns which was rotated to select the 9.55 micron line. The FIR hemispherical cavity consisted of a 28 cm diameter concave gold-coated mirror having radius of curvature 376 cm, and a 6 cm diameter plane mirror. Both mirrors could be translated by micrometer so the cavity length could be varied over a few cm in the neighbourhood of 373 cm. The cavity was thus marginally stable. Radiation was coupled out by a 25 micron thick Melinex beam splitter at 45° to the cavity axis located next to the plane mirror. Its reflection coefficient for 0.5 mm perpendicularly polarized radiation is calculated to be about 20% assuming an index of refraction for Melinex of 1.8[8]. To limit FIR oscillation to fundamental (TEM_{00}) modes, a diaphragm whose diameter of 2.3 cm made the cavity Fresnel number just less than unity, was placed adjacent to the plane mirror.

The optical cavity was enclosed within a glass cylinder filled with CH_3F gas at a pressure near 1 torr. Pumping radiation from the CO_2 laser entered the cavity through a negative f = 150 cm lens that caused it to diverge so that following reflection on a small aluminium mirror it filled an area of diameter 20 cm at the large concave mirror. From there it was reflected and re-converged down the cavity, and what remained unabsorbed by the CH_3F was scattered by the end plate near the diaphragm. This arrangement ensured that the volume illuminated by the pump approximately coincided with the fundamental mode volume.

A calorimeter* measured the FIR output energy and a Si-W point-contact diode† was used to record the pulse shape. A typical FIR cavity pulse, shown in Figure 2a, displays strong modulation and lasts approximately 1 microsecond. Modifying the TEA laser pulse by selectively amplifying its tail, as shown in Figure 2b, resulted in an improvement in conversion efficiency and pumping pulses having enhanced tails were used throughout this investigation.

The dependence of FIR output energy on pump energy and CH_3F pressure is shown in Figure 3a. Pump pulses were attentuated with polythene sheet, and for each pump energy, a particular gas pressure was found which gave the maximum FIR output. This optimum pressure increased from 0.2 to 0.6 torr as pump energy increased from 2 J to 42 J. Saturation of the output with increasing pump energy is displayed in Figure 3b where FIR energy is plotted against pump energy for various fixed values of the pressure. The conversion efficiency from pump to FIR energy decreases as pump energy increases, the maximum being 0.06% found at 2 J input, falling to 0.015% at 42 J input. These values are up to an order of magnitude smaller than the efficiency found in the super-radiant laser[(4)].

The FIR pulse length decreased with decreasing pump energy. The shortening occurred almost entirely at the leading edge of the pulse and

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*Calibrated at the National Physical Laboratory, UK, to better than 10% accuracy. Sensitivity was 27 mV J^{-1}.

†Made to contract by Custom Microwave Components, 7065 Overbrook Drive, Longmont, Colorado, USA.

was observed at all operating pressures, but was most apparent at high pressure (around 1 torr).

Pressure also had a slight influence on pulse length, the longest pulses appearing at the lowest pressures.

Maximum pulse energies of 6.5 mJ were measured for pulses whose lengths were typically 1.2 microsec, implying average powers of 5.4 kW and peak power in excess of 10 kW.

Changing the cavity length by translating one of the mirrors produced a periodic variation in the FIR output consistent with a wavelength for the cavity radiation of 496 microns. The beam profile, measured by traversing the calorimeter across the horizontal and vertical diameters of the output window is closely approximated by the convolution of a Gaussian with a rectangle representing the calorimeter sensitive area, as shown in Figure 4. The Gaussian profile is consistent with the expectation based on the low Fresnel number of the optical cavity, that the FIR laser is oscillating in fundamental modes only. This is confirmed by the modulation of the FIR pulse, which displays a predominant beat frequency of 40 MHz, the fundamental mode spacing of a 373 cm cavity. When the 2.3 cm diaphragm was withdrawn, FIR pulses showed a predominant beat frequency near 20 MHz which can be identified with beats between low order transverse modes.

A scanning metal-mesh Fabry Perot interferometer with Golay cell detector[(4)] was used to confirm that only the 496 micron line was present and to construct a spectrum of the FIR radiation from a sequence of laser pulses. For band width measurements the free spectral range was 360 MHz and the instrumental width was about 28 MHz. At pressures up to 0.4 torr, the overall width was between 50 and 100 MHz, and this increased to and appeared to remain constant at 150 MHz beyond 0.8 torr. As the longitudinal mode spacing is 40 MHz, these results imply that at lower pressures predominantly three modes are oscillating, with this increasing to 4 or 5 as the pressure increases. Pump energy was fixed at 35 J throughout the bandwidth measurements.

Spectral measurements lacked time resolution and the several modes contributing to the time-integrated spectrum may not all have been present simultaneously throughout the pulse. Point-contact diode time-resolved oscillograms show evidence of changes of phase in the beat signal occurring during the lifetime of the pulse, and these can be interpreted as one mode dying as another mode grows. So at any instant, the FIR bandwidth may be only two modes wide though its time-integrated spectrum indicates a width of 3 or more modes.

The divergence of the FIR output was derived from a measurement of the energy profile in the focal plane of a 32 cm focal length TPX lens made with the calorimeter. 95% of the energy was found to lie within about 30 mrad, which is in good agreement with the divergence predicted for TEM_{00} modes in this cavity. A grid polarizer was used to investigate the state of polarization of the FIR beam and it was shown to be polarized perpendicular to the plane of polarization of the CO_2 laser pumping radiation, again according to expectation.

Our conclusions may be summarized as follows. Optical cavity operation of a CH_3F laser pumped by up to 42 J of 9.55 micron CO_2 TEA laser radiation has produced pulses of FIR output at 496 microns confined to a few TEM_{00} modes of the hemispherical cavity. The output beam has diffraction limited divergence and is plane polarized perpendicular to the pump radiation. The pulses last about 1 microsec, and contain up to 6.5 mJ of energy delivered at peak powers in excess of 10 kW.

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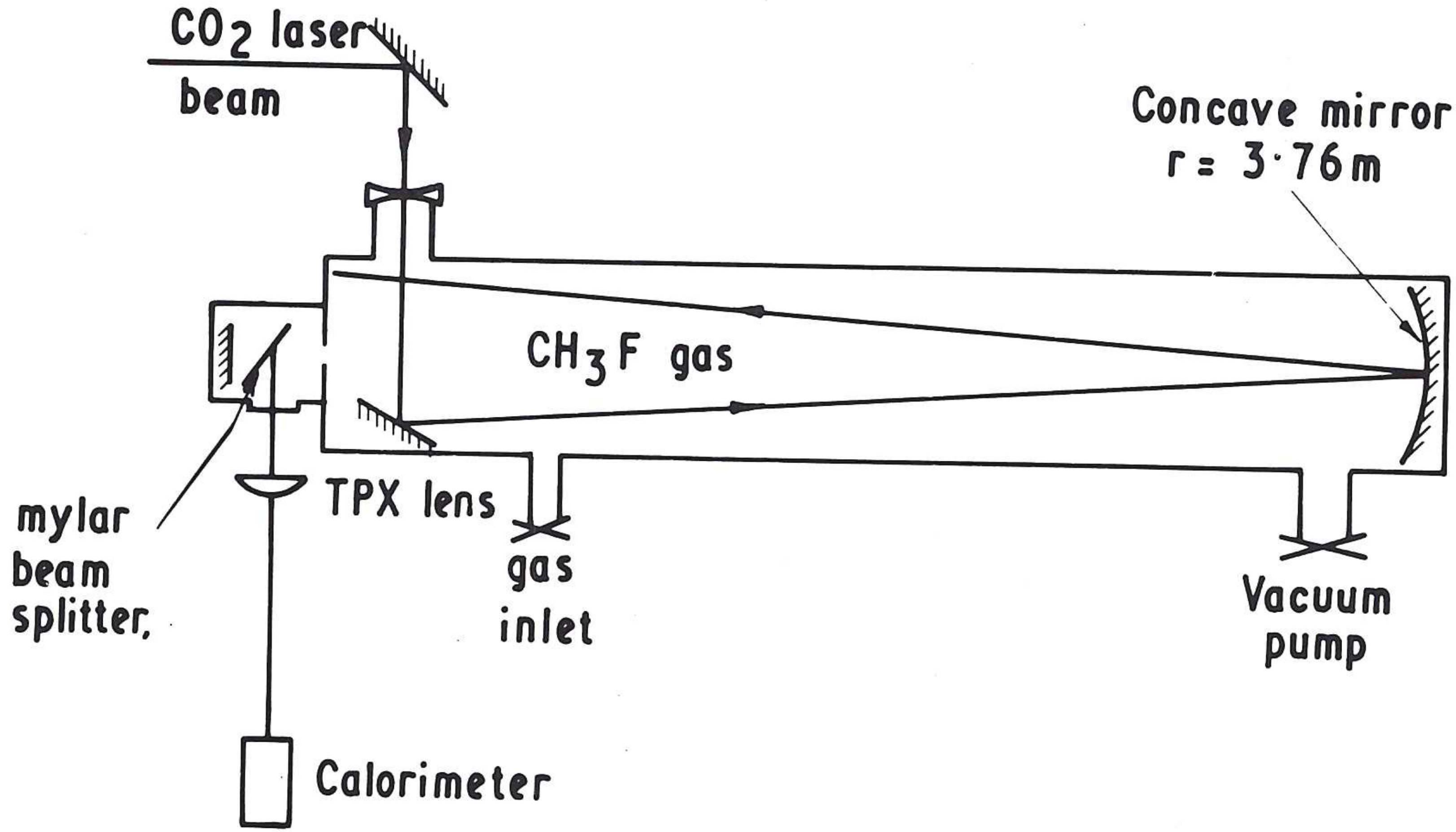


Fig.1 CH_3F laser hemispherical optical cavity. Small plane mirror diameter 6 cm, stopped down to 2.3 cm by fundamental mode selecting aperture. Large concave mirror (radius 376 cm) diameter 28 cm, central 20 cm illuminated by pump radiation.

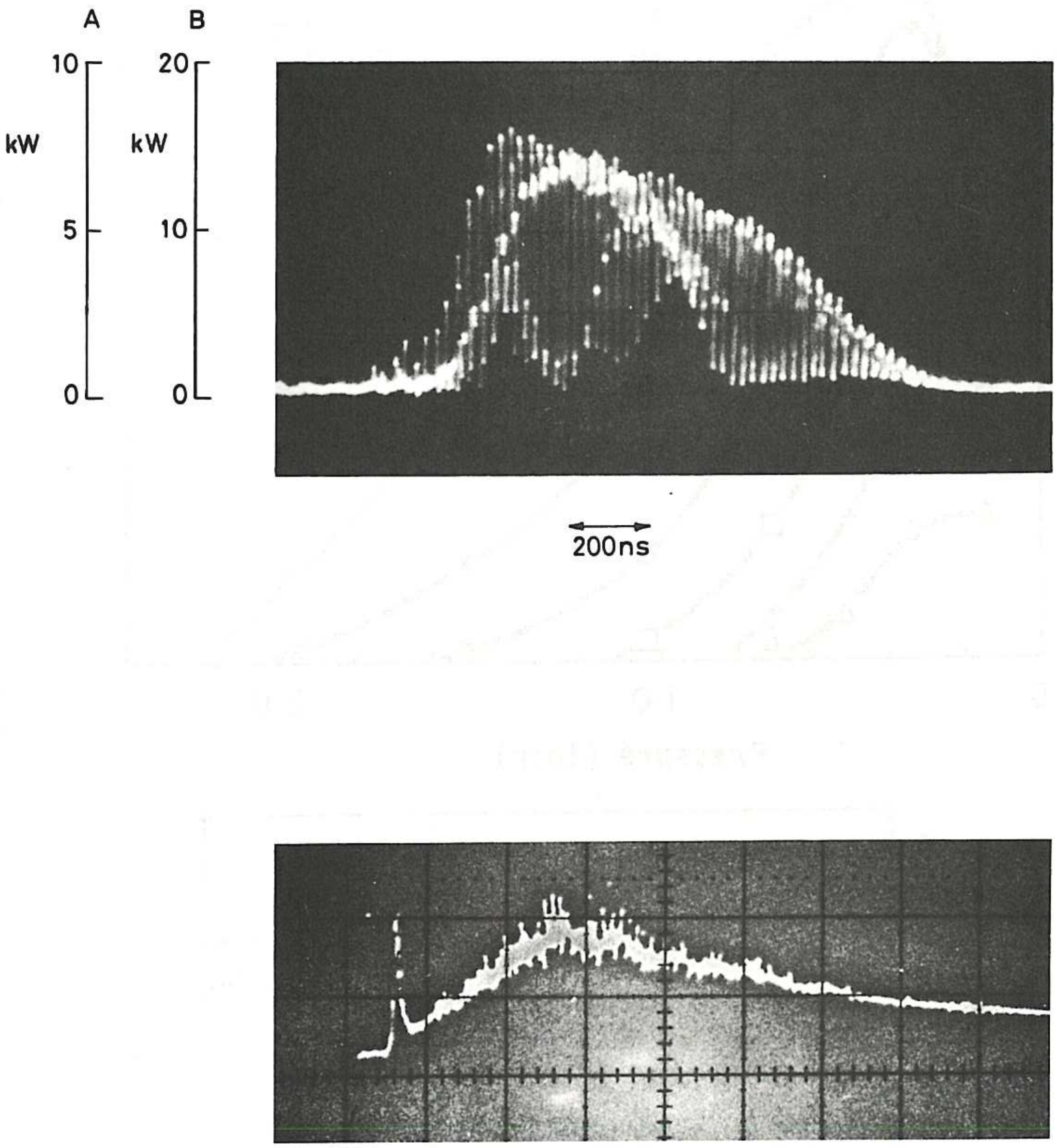
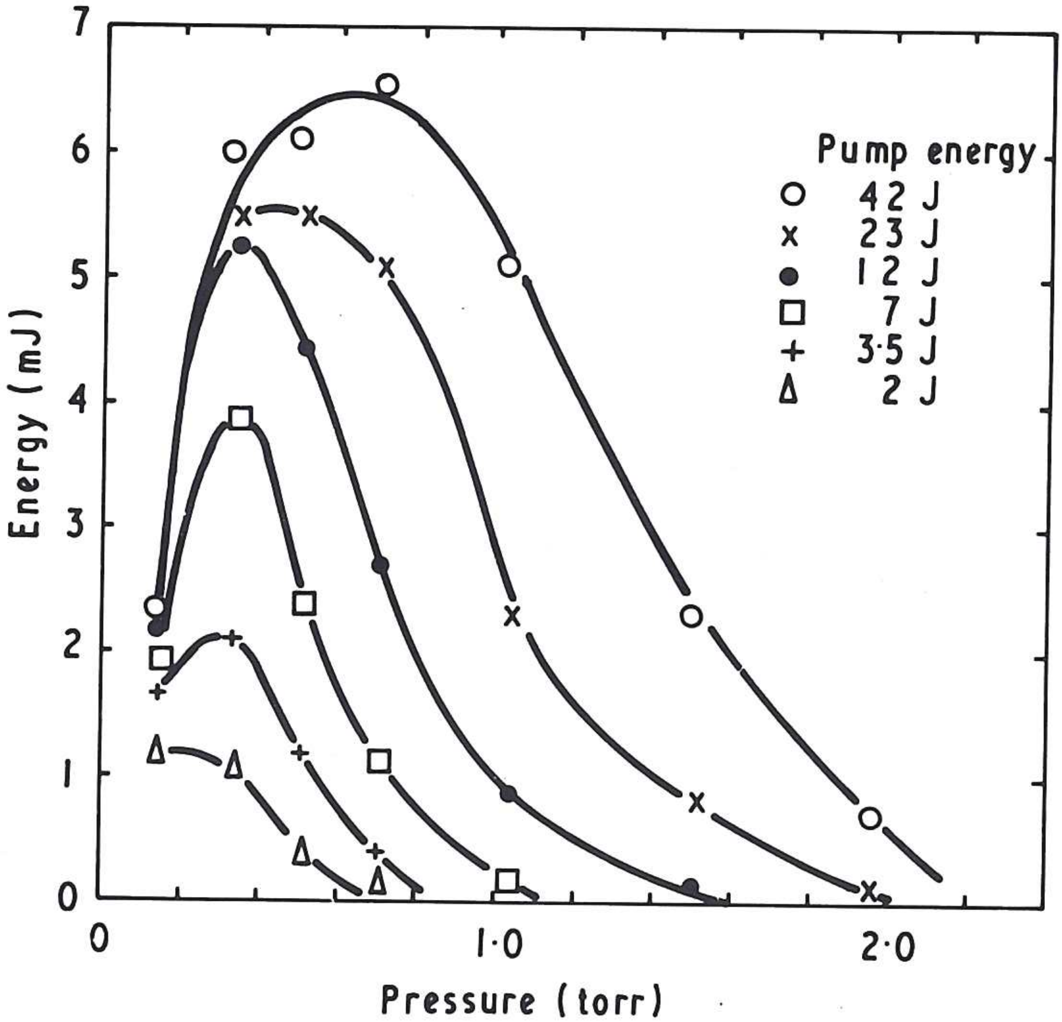


Fig.2 (a) FIR optical cavity pulse. Beat frequency = 40 MHz. kW scale A calculated by counting squares under pulse envelope. This procedure underestimates power because it ignores modulation. If modulation is 100% and mark-space ratio 1:1 scale B results. 200 n sec div^{-1}. (b) CO_2 TEA laser pumping pulse showing selectively amplified tail found to give improved conversion efficiency. 500 n sec div^{-1}.



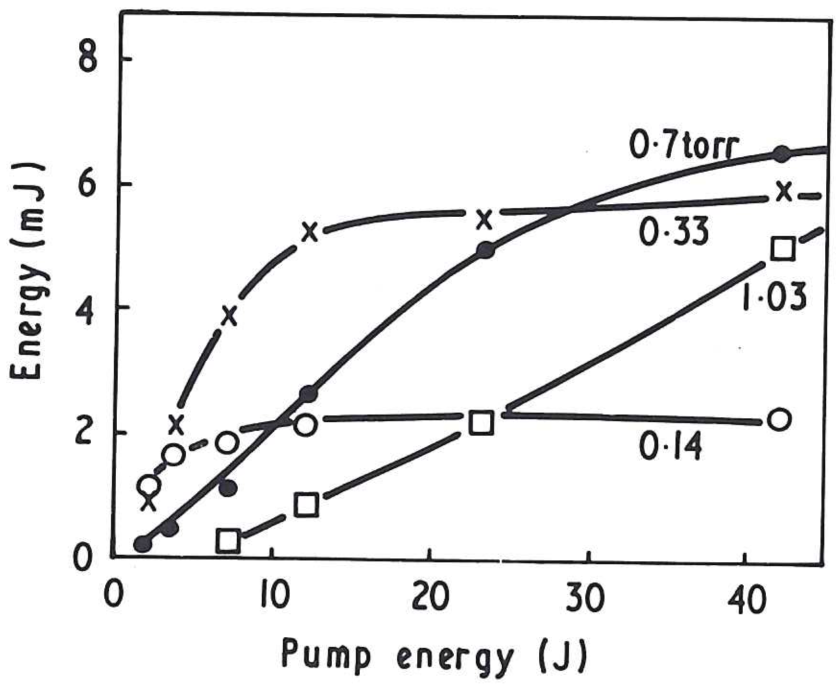


Fig.3 (a) FIR pulse energy dependence on CH_3F pressure, for various values of CO_2 beam pump energy illustrating optimum pressure effect. (b) FIR pulse energy dependence on CO_2 pump energy for various values of CH_3F pressure, illustrating saturation effect.

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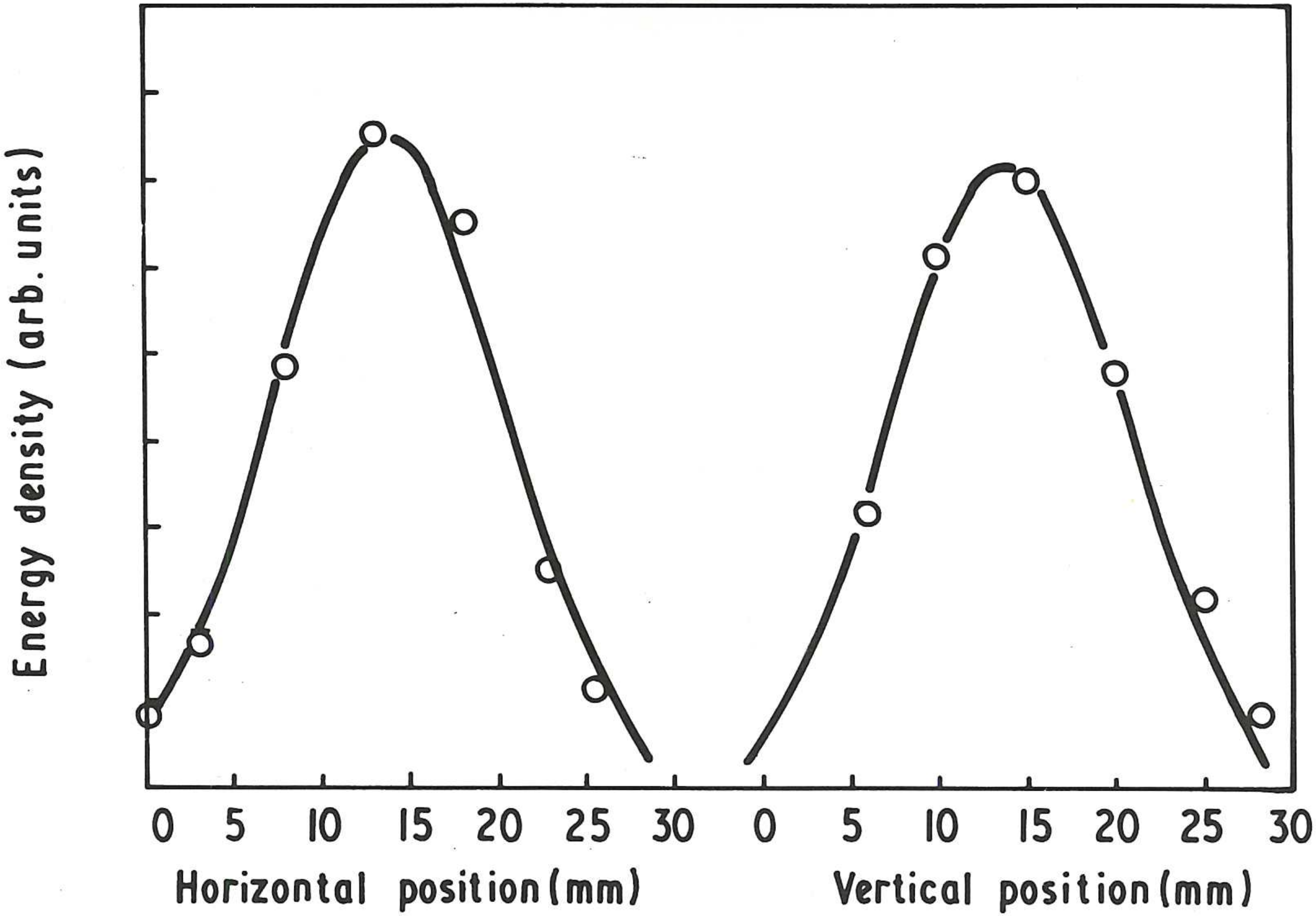

Fig.4 FIR output beam profile. Curves are Gaussians convolved with rectangle representing sensitive area of a calorimeter. Confirms fundamental mode character of FIR pulse.