APPENDIX 6

REVIEW OF FIR LASERS AND TABLE OF FIR WAVELENGTHS

A6.1 REVIEW OF OPTICALLY PUMPED GAS LASERS

The optically pumped gas laser relies on the absorption of 'pump' radiation to transfer molecular population from a lower to an upper energy level. This shift can produce population inversion and hence stimulated emission to a third level. In the case of a gas laser, the absorbing medium is placed within an optical resonator which confines the injected pump radiation, but allows a small fraction of the emitted power to be coupled out.

The prime reason for choosing the CO_2 laser as the source of pump radiation is the large number of gaseous molecules which are capable of absorbing the CO_2 power in an efficient manner. Furthermore, since the most efficient scheme involves a one-for-one correspondence between absorbed and emitted photons, the frequency discrepancy between the two needs to be small to preserve power efficiency. Optical pumping with a laser is generally undesirable because it is inefficient and expensive. In many cases, however, this is the only approach: for FIR lasers the excitation must be specific because the energy separation between levels is less than that corresponding to thermal motions. Fortunately, the CO_2 laser is reasonably efficient (ca 20%) and, in its many isotopic variants, will generate more than 250 spot frequencies in the band from 25 to 35 THz at power levels up to 4 kW cw or several tens of Joules pulsed.

Optical pumping of these gaseous molecules to produce the required FIR radiation is a well-understood process. Typically, a monochromatic beam from a CO_2 laser is used to pump a single narrow absorption line, which results in a vibration-rotation transition. The resulting population inversion between adjacent rotational states and the large transition matrix elements provided by the permanent dipole moment both lead to appreciable gain (1% m^{-1} to 1% mm^{-1}) and stimulated emission from pure rotational transitions throughout the FIR spectrum. This simple model applies to pulsed as well as cw lasers when the absorption line and infra-red pump source are coincident to within 100 MHz. For off-resonant excitation, the molecular population transfer does not follow this two step scheme, but involves direct transfer from level 1 to 3 with the aid of an intense electric field at the pump frequency, giving rise to the Raman effect.

Applying these techniques has led to the generation of some 2,000 spot frequencies in the 140 to 7500 GHz frequency band. For FIR lasers pumped by low-power sources, the gain bandwidths are only ±2 MHz, depending on the contribution of pressure- and Doppler-broadening to the overall gain width at typical operating pressures of approximately 10^{-1}mB.

The optically pumped Model FIRL100 (Far Infra-Red) laser is based around a stable large-bore dielectric waveguide resonator which gives the system maximum flexibility over the 40 µm to 1 mm wavelength range.

A6.2 FIR WAVELENGTHS

Supplied with the laser system is a table of all known lines (upto ca. 1987). This is not all the lines which can be achieved with the supplied system but is simply provided as a reference. In addition there is a book published by Springer Verlag which also lists known FIR lines and this should be referred to. *Millimetre and Submillimetre Wavelength Lasers - A Handbook of cw Measurements.* by Nigel Douglas. Springer Verlag, Optical Sciences Series, Vol. 61 ISBN 3 540 50827 9

Table A6.1 provides a list of known lines seen with Edinburgh Instruments FIR lasers and some of these may be achievable under the correct operating conditions (eg. correct gas pressure/cavity length and most importantly for weaker lines through the use of a sensitive, fast detector.)

These lines have either been seen at Edinburgh Instruments or by users of its equipment (up to February 1992).

TABLE A6.1 : FIR Wavelengths

List of FIR lines seen with a range of Edinburgh Instruments FIR lasers (either FIRL100, 295 or 195 pumped mainly by ca 50 W CO_2 pump source).

Key to Table

pyro : suggests powers < 1 mW, and a pyroelectric detector was used.

Golay: suggests powers < 0.1 mW and a Golay detector was used.

Metal : indicates a metal waveguide was used (since at wavelengths greater than ca 600 µm glass pyrex is increasingly lost).

M : powers in the 1-10 mW region

^{13}C : indicates that CO_2 laser was sealed off and utilised the Carbon 13 isotope of CO_2.

MOLECULE	WAVELENGTH (mm)	CO_2 PUMP LINE	MAXIMUM TYPICAL POWERS (mW)
CD_3OD	41	10R18	ca 1
CD_3OH	53.8	9R34	pyro
CH_3OH	67.5	9R18	ca 10
CH_3OH	70.6	9P34	20
$^{15}NH_3$	78.5	10P24 (^{13}C)	pyro
CH_3OH	86.2	9R 8	10
CH_3OD	86.7	9R28 (^{13}C)	1
CH_3OH	96.5	9R10	90
CH_2F_2	109.2	9R24	pyro
$^{15}NH_3$	112.3	10P14 (^{13}C)	M
CH_2F_2	117.7	9R20	pyro
CH_3OH	118.8	9P36	150
CH_2F_2	122.4	9R22	40
CH_3OH	133.1	9P24	1
CH_2F_2	133.9	9P22	pyro
CH_2F_2	139.9 (cascade?)	9P22	pyro
CD_3OD	143.8	9P18 (^{13}C)	pyro
$^{15}NH_3$	152.7	10R18 (^{13}C)	150

CH_2F_2	158.5	9P10	pyro

MOLECULE	WAVELENGTH (μm)	CO_2 PUMP LINE	MAXIMUM TYPICAL POWERS (mW)
CH_3OH	163	10R38	36
CH_3OH	164.6	9P16	pyro
CD_3OD	184	10R24	30
CH_2F_2	184.3	9R32	150
CH_2F_2	193.9	9R22	10
CH_2F_2	214.6	9R34	100
CD_3OH	221	9P36 (^{13}C)	pyro
CD_3OD	255	10R36	5
CD_3OH	292.1	9P38	10
CH_3Cl	333.9	9P42	pyro
CD_3OD	355.5	10R16	2
$^{15}NH_3$	373.4	10R42	50
CD_3Cl	383.2	9R34	25
$^{15}NH_3$	388.5	10R10 (^{13}C)	M
HCOOH	393.6	9R18	40
HCOOH	418.6	9R22	30
HCOOH	432.6	9R20	40
CD_3Cl	443.3	9P10	M
CH_3I	447.1	10P18	M
CH_3F	496.1	9P20	M
HCOOH	513	9R28	20
CD_3OH	530.4	9P20 (^{13}C)	pyro
CH_3OH	570.6	9P16	M
$C_2H_2F_2$	662.8	10P24	pyro
$^{13}CD_3I$	690	10P10	20
HCOOH	742.6	9R40	2
HCOOH	744	9R24	pyro
$^{13}CD_3I$	806	10P12	4
$C_2H_2F_2$	889	10P22	pyro
CH_3OD	917	9R24 (^{13}C)	pyro (Metal)
CH_3Cl	944	9R12	pyro (Metal)
$C_2H_2F_2$	1020	10P14	pyro (Metal)
$^{13}CH_3F$	1221.9	9P32	1 (Glass) 7 (Metal)
CH_3Cl	1886.7	9P26	Golay (Metal)

Other FIR lines not uniquely identified

MOLECULE	WAVELENGTH (μm)	CO_2 PUMP LINE	MAXIMUM TYPICAL POWERS (mW)
CH_3OH	43.1 or 53.5	10R36	pyro
CH_3OH	100/194 or 209	9R14	pyro
CH_3OH	62/69/77	10R16	3
CH_3OH	not listed (short wavelength)	9P28	pyro
CH_3OH	unknown	10P24	pyro