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APPLICATIONS OF AN INTENSE TUNEABLE FAR INFRA-RED LASER:
Extended Abstracts of a One-Day Meeting held at Daresbury Laboratory,
26th November, 1980.

Compiled by

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Daresbury Laboratory.

MAY, 1981

Science Research Council

Daresbury Laboratory

Daresbury, Warrington WA4 4AD

APPLICATIONS OF AN INTENSE TUNEABLE FAR INFRA-RED LASER

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SCIENCE RESEARCH COUNCIL
DARESBURY LABORATORY

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INTRODUCTION

by

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Free electron lasers became reality with the experiment by Madey[1] in which the 43 MeV Stanford Linac drove a 3.4 μm laser with a mean power of 1 W. This experiment opens up a vast range of possibilities for development and applications. On the development side there is the possibility of extension to higher powers. A recirculatory device of some sort would be needed raising problems of electron beam stability under lasing conditions and requiring considerable study. The potential powers from recirculatory devicee are huge. Because of the large r.f. power that can be injected into an electron beam, only a few % efficiency gives kilowatts of power to the laser.

Next there is the possibility of operation in different wavelength ranges. The most exciting and difficult prospect is a laser in the near U.V. Such a device would be expensive and would almost certainly involve recirculation of the electron beam but would hold out revolutionary prospects for laser chemistry and physics. A less dramatic, but important extension is to the far I.R. This is the course that Daresbury has taken. Requirements on the electron source are less demanding at longer wavelengths and the availability of an ideal electron source in the former NINA linac all pointed in this direction. A Study Group has been considering the theory for some time and has produced the FELIX proposal for a laser on which Mike Poole will report.

Briefly summarised FELIX will operate as a tuneable source in the range 75-150 μm with mean power 10 W and peak power 10^7 W. The bandwidth will be ≈ 0.5% dictated by the pulsed nature of the source and the radiation well collimated with second order coherence properties typical of stimulated emission. The radiation will be plane polarised and have a precise time structure which can be used as a clock on a nanosecond time scale. A similar but less powerful device is under development by Bell Laboratories for use in solid state FIR experiments.

The estimated capital cost of FELIX is of the order of £0.5M, a figure which would be very much greater were it not for the availability of the NINA injector. (A completely new linear accelerator would cost around £2M.)

The objectives of the FELIX project will be, firstly as a test bed for free electron laser theory which though highly developed is currently lacking in experimental data. Secondly as a source of FIR radiation for experiments and it is with the latter applications that we are concerned here. Figure 1 taken from Martin and Mizuno[2] shows the power and range of tuneable FIR sources together with FELIX's characteristics. This makes clear the radical nature of the proposed source.

We hope to collect views on the usefulness of the device, to stimulate discussion and above all to set in motion the development of really radical experiments which are not possible with present sources. This meeting is the first step in an iterative process. We welcome further comments for those who attended the meeting and from those to whom the proceedings have been circulated.

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FIGURE CAPTION

Fig. 1 Output powers of tuneable sources that can generate 1 mW or more continuously in the sub-millimetre spectrum.

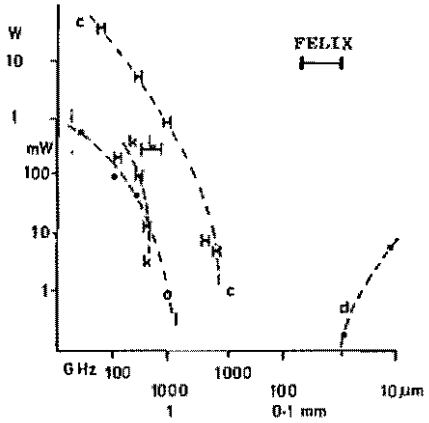

Fig. 1

FREE ELECTRON LASERS IN THE FAR INFRA-RED

BY

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In the four years since operation of a free electron laser (FEL) amplifier was first demonstrated experimentally at 10.6 μm by the Stanford University group[1] interest in such devices has increased rapidly. Although this team soon operated their apparatus as a 3.4 μm ocillator[2] no further experiments have since been undertaken on this or any similar device. However a Naval Research Laboratory/Columbia University collaboration culminated in 1978 in successful operation of a FEL at 400 μm[3], although employing a different operating regime making use of collective plasma effects.

A wide variety of theoretical FEL treatments has become available, including techniques of quantum electronics, but it is now clear that the FEL should be seen as an evolution from earlier classical microwave devices such as the travelling wave tube, extending their output to shorter wavelengths. Most of the basic behaviour of the Stanford device can in fact be explained with a simple classical theory of single particle interaction between electron and electromagnetic wave. However some of the Stanford FEL characteristics were not predicted by such theory, in particular effects associated with propagation of radiation pulses, and more comprehensive theories are also required to analyse advanced and complex FEL designs that can now be envisaged. A large literature on FEL theory now exists, allowing detailed prediction of anticipated operating properties of FELs that might be built, but unfortunately these theoretical developments have yet to be supported by a set of experimental data.

In order to contribute to the development of the FEL a test bed experiment has been proposed by a study group based at the Daresbury Laboratory of the Science Research Council. This would be a flexible, general purpose facility not only supplying data able to be extrapolated to a wide variety of FEL designs, but also giving essential practical experience in the operation of these new radiation sources. The proposed

Free Electron Laser Investigation Experiment (FELIX)[4] has a chosen output wavelength specified to be tuneable initially from 75-150 μm and should provide pulses with saturated peak power up to 10 MW, the mean power then being several watts. If approved FELIX will also be a unique far infra-red source in its output range, with very high power and tunability of coherent radiation, and could be utilised for research, although this is not its principal objective. In any event the FELIX parameters are typical of those of most likely future FELs dedicated to far infra-red applications, since the designs are dominated by available electron sources.

FELIX employs conventional technology wherever possible, and the periodic magnet at its heart has a plane polarised field producing a corresponding radiation property. The electron beam is provided by a 50 MeV linear accelerator once used as injector to the synchrotron NINA that has now been closed down, and this electron source must therefore be renovated and recommissioned incorporating modifications required for the FEL. Its time structure determines the corresponding pulse properties of FELIX, including the line width of the optical cavity, although conventional optical techniques can be used to modify the properties of the multimode oscillator. Some of the more important FELIX parameters are summarised in Table 1.

With the original apparatus the FELIX tuning range can probably be extended to 50-200 μm if necessary. Longer wavelengths require a new periodic magnet to avoid excessive diffraction losses in the confocal cavity, but the electron source will set a limit of about 300 μm. Reduction of minimum output wavelength will be severely limited by the associated reduction in FEL gain, but a new magnet might allow operation down to about 20 μm, to be confirmed by operating experience.

Far infra-red FELs are under development at a number of foreign laboratories, and three examples will illustrate this work. Bell Laboratories (Murray Hill) plan a device with output 100-400 μm and power levels comparable with FELIX, having pulse structure set by its microtron electron source also similar to FELIX. At the Santa Barbara Quantum Institute FELs based on electrostatic accelerators delivering d.c. electron beams are being developed, making possible extremely high average output powers at

wavelengths of several hundred microns with very narrow linewidth. Finally both the Naval Research Laboratory and Columbia groups are continuing experiments on collective FELs at far infra-red and sub-millimetre wavelengths to produce extremely high peak powers, although in short (< 1 μs) pulses with poor duty cycle.

In conclusion it seems clear that construction of free electron lasers operating in the far infra-red at high power levels and continuously tunable over a wide range is feasible with existing technology and knowledge of FEL theory. Nevertheless such devices will require extensive experimental studies before reliable research sources with optimum properties can be established.

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Table 1

Specified output range (initial)	75–150 μm
Linewidth (unmodified)	0.5 %
Saturation power, peak	10 MW
mean	10 W
Repetition rate	25 Hz
Macro-pulse length	1–2 μs
Micro-pulse length	60 ps
Pulse train separation (408 MHz)	2.5 ns

TUNABLE FAR INFRA-RED SPECTROSCOPY OF SEMICONDUCTORS

by

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Far infra-red spectroscopy is being extensively employed to study a variety of phenomena in semiconductors including cyclotron resonance of free carriers, free and bound excitons, electron-hole droplets, impurity states and the charged impurity analogues of the negatively charged hydrogen atom (D^- and A^+ states). At present, fixed frequency coherent sources such as optically-pumped gas lasers or spectrometers based on black-body sources are being used for such studies. At best free electron lasers such as FELIX would seem to offer only the prospect of modest improvement in signal-to-noise figures for conventional spectroscopy and this advantage is unlikely to offset the high capital expenses and the disadvantages associated with operation at only a few central locations. Consequently cheaper and smaller scale alternatives such as sources utilising cyclotron emission from semiconductors, where powers of the order of 1 μW tuneable from 10 to 500 cm^{-1} are available would seem preferable in scale and cost for most conventional spectroscopic applications.

However the combination of tunability, high power and the ability to generate short pulses gives free electron sources the potential to open up new fields of study and the exploitation of such sources as they become available will be limited only by the ingenuity of the individual experimenter in extending the presently recognised range of experiments. One can foresee for example that it would be possible by pumping individual phonon combination bands to generate high concentrations of non-equilibrium phonons at particular frequencies right out to the edge of the Brillouin zone. It would then be possible to modify such phenomena as the magneto-phonon effect which depend on the detail of the electron-phonon interaction. It would also be possible to measure the phonon lifetimes and their modification when in resonance with electrons.

Possible applications can be divided into the intermediate (~ 1 kW peak power) and ultra high power (~ 10 MW peak power) regimes.

The tunability would allow the precise excitation and saturation of most free electron, impurity and excitonic transitions even at fairly moderate power levels - leading to such effects as self-induced transparency, the possibility of stimulated emission and a variety of associated non-linear optical effects. It would be possible to induce optically the polarisation catastrophe (metal-insulator transition). Weak electronic or local-phonon absorption resulting from low concentrations of impurities would be detectable by photoconductive or bolometric techniques although background multiphonon absorption would ultimately limit the sensitivity of detection. At the very high levels capable of being generated by the free electron laser, annealing or crystallisation of the lattice would be possible. Localisation of the annealing effects could be produced by focusing the radiation or by the spatial variation of the impurity or defect concentration. Finally one should mention in passing that photochemical dissociation of selected molecules would be of considerable interest as a future processing technique for the semiconductor industry. In this application the high power and tunability of free electron sources would be of great value although the frequencies of interest are initially likely to be considerably greater than those proposed for FELIX.

APPLICATION OF FELIX TO STUDIES OF SEMICONDUCTOR INVERSION LAYERS

by

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It is probable that such a facility as FELIX will inaugurate a new generation of experimentation, which will allow a more comprehensive investigation than has hitherto been possible.

Some of the topics which have been investigated include studies of transitions between quantized subbands, two dimensional plasmons, cyclotron resonance, and two dimensional impurity bound states. Experiments are performed using a laser and adjusting the level separation and carrier concentration until resonance occurs or by a spectrometer combined with signal averaging techniques. FELIX would considerably simplify the experimental process and would greatly assist the separation of such phenomena as the competition between correlation and disorder.

LOW FREQUENCY VIBRATION IN AMORPHOUS MATERIALS

by

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Vibrational spectroscopy has played an important part in supporting the random network model for covalent amorphous solids[1]. Infra-red absorption, Raman and inelastic neutron scattering are fairly well understood. Over most of the spectrum the essential short-range character of the modes ("bending", "stretching", etc.) is similar to that of a corresponding crystal, as is the density of states, but there are no strong effects analogous to k-selection.

However, the $\omega \to 0$ limit is clearly a special one, since one expects the continuum limit to be approached, much as in a crystal, and in some sense the k-vector is re-established as a quantum number. This "Debye regime" has attracted the attention of experimentalists and theorists from time to time. It has proved difficult for the former and inscrutable to the latter. For IR absorption the facts are -

(1) At low frequencies, but above 10 cm^{-1}, the absorption scales as ω^2 (i.e. as the Debye density of states). It can be correlated with the T^3 term in the specific heat.

(2) Below 10 cm^{-1} there is some indication of a stronger (ω^4?) dependence, but there is also a significant temperature dependence.

Most theoretical models suggest an ω^4 dependence, but possibly only up to some critical frequency. It must be said however that there is no convincing underlying formalism for such models - they tend to have an *ad hoc* character. Ziman[2] has commented on the lack of progress on this apparently simple problem.

In my opinion, the tidying-up of the theoretical picture is more urgently required than more data! If we can understand properly how to marry the Debye regime to the more chaotic picture at high frequencies, and the possible relevance of tunnelling modes and/or Anderson localisation, then more and better data would be rewarding.

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FIGURE CAPTIONS

Fig. 1 Phonon density of states as determined from neutron scattering, reduced Raman spectrum and far infra-red absorption for amorphous Ge at 300 K as functions of wave number.

Fig. 2 Infra-red absorption (solid lines at 300 K; dashed lines at 10 K).

Fig. 3 Product of refractive index, n, and absorption coefficient, α, as a function of frequency for various amorphous solids.

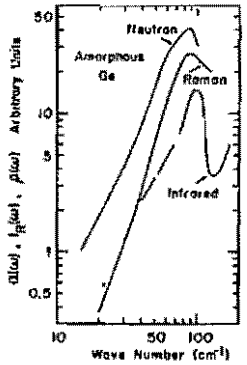

Fig. 1

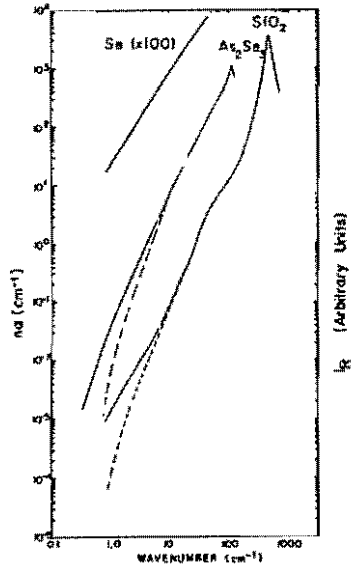

Fig. 2

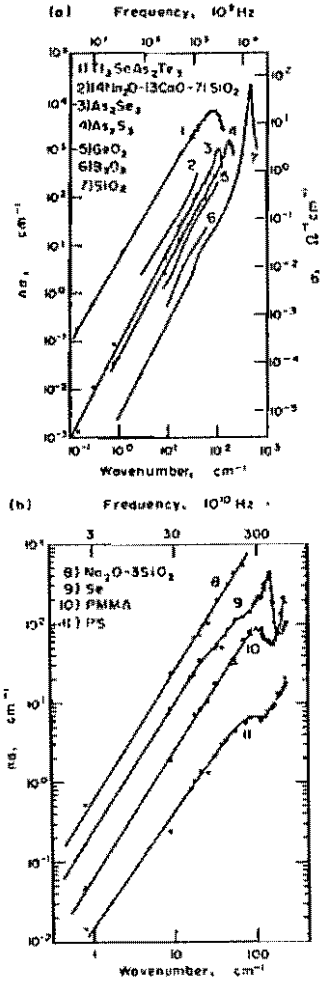

Fig. 3

VIBRATION AND ROTATION AT SURFACES

by

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The most obvious problem confronting IR spectroscopy at surfaces is the very small number of molecules present. Even at monolayer coverage we are dealing with only ~ 10^{14} to 10^{15} molecules, and this small number taken together with the tiny dipole moments of many molecules places severe limitations on sensitivity. Carbon monoxide is one of the few molecules with a respectable moment and a very high percentage of studies rely on this molecule.

Other alternatives are available. Electron energy loss spectroscopy in particular has good sensitivity because it interacts with only the immediate surface regions, but is severely limited in resolution (~ 5 meV) and cannot be used to study losses of much less than 20 meV because of background problems. Atom scattering has recently been used with good sensitivity but is not yet a widely used or proven technique. Raman studies suffer from an even greater lack of sensitivity than IR studies, apart from certain freak sensitivities in particular metals where giant Raman resonances are seen, which leaves IR as a flexible high resolution probe provided only that an intense source is available.

What experiments could a good IR source be used for? Intensity would enable currently invisible modes to be seen. The CH stretch frequency, which is obviously quite basic to organic molecules, cannot be seen at present and there are many other instances even amongst simple molecules. One particularly interesting area of application is to the observation of low frequency modes. Much of the interest in surface chemistry lies in the interaction with the substrate, and substrate modes are too low in frequency to be seen with current techniques. The "softening" of a particular phonon mode may bé the precursor to a bond breaking or a change in the molecular configuration, bu any significant softening takes the frequency below the range accessible with current technology.

An example of mode softening may be found in the reconstruction of the tungsten (001) surface. At higher temperatures this surface has the symmetry expected from truncation of a bulk tungsten crystal, but on cooling reconstructs, a process driven by the need of the rather open (001) surface of body centred cubic materials to find more near-neighbours for the surface atoms. Observation of a soft phonon precursor would give much more information about this system.

Another area not presently experimentally accessible is the rotational spectrum: the observation of molecular rotations for molecules such as pyridine about the axis of the bond to the surface may lead to significant refinements in the determination of bond lengths and angles. High resolution vibrational spectroscopy of these larger molecules would also lead to the possibility of complete normal coordinate analysis. Changes in the shapes of molecules on chemisorption is an important but unexplored research area.

Finally, the brightness of the source and its picosecond pulse time open up the possibility of real time spectroscopic investigations of short-lived transients during kinetic processes, such as adsorption, desorption, diffusion and catalysis. Excited state "hot" molecule adsorbed transients have been postulated as important intermediates in these processes, but no experimental methods are available with sufficient sensitivity to observe them.

POSSIBLE APPLICATIONS OF A FAR INFRA-RED FREE ELECTRON LASER TO THE STUDY OF MOLECULAR SYSTEMS

by

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Applications of a very high powered, tunable and pulsed far infra-red source might be anticipated in three different areas.

(i) There are a wide range of chemical and biochemical systems which would benefit from an improvement in (cw) source intensity. This region is well known[1,2] for the observation and characterisation of co-operative, dynamic processes arising in a wide variety of compounds ranging from simple polar liquids [3,4] to biopolymers[5]. (In many instances dilution studies are essential[3,4] in order to attempt to separate the various contributing phenomena.) There are also a number of potentially very interesting systems where one would like to examine a very weak spectrum against a highly absorbing solvent or substrate. These include aqueous solutions[6], surface adsorbed species[7,8] and hydrogen bonded complexes[9]. In lots of these cases it is virtually impossible to obtain reasonable spectra with currently available sources. Increased source intensity would undoubtedly greatly improve our understanding of such systems.

(ii) Since a wide variety of the kind of chemical systems mentioned above have associated with them dynamic processes in the μs and ns time range[10], it is extremely important to make use of the time structure of the pulsed source. Since this comprises micropulses of 60 ps width and 2.5 ns separation, it follows that processes with time constants in the 100 ps to 2.5 ns may be studied. Such a time scale would be appropriate for example for the study of (a) protein rotation in lipid bilayers (b) internal rotations and conformational changes within the protein molecule and (c) 'flexing' of the hydrocarbon chains in phospholipid membranes. This particular part of the spectrum has the advantage that one need not use[11] a fluorescent 'tag' chromophore. More naturally occurring proteins may therefore be studied. There is also the possibility of studying considerably slower processes since

macropulses from a 'FELIX' type source would have a width of 4 μs and a separation of 0.04 s. This might allow, for example, the investigation of the dynamics of protein denaturation and that of phospholipid molecule interchange at a membrane surface. One problem with such measurements is the need for development[12] of very fast (i.e. ps) detectors operating at 150 μm wavelengths. It is felt, however, multipulse train optical delay techniques such as those employed at visible frequencies[13] might be employed to alleviate this problem.

(iii) With such high powers available it is clear that a whole exciting new area of science could be opened up by the study of non-linear phenomena at long wavelengths[14] (i.e. phenomena depending[15] on E^2 and E^3 terms in the induced dipole moment expansion). The effects of an external electric field on infra-red and far infra-red spectra have been studied[16,17] to some extent. With a laser source such as that envisaged in the FELIX project one would inevitably observe greatly enhanced 'effects' (indeed, for a lot of molecular systems one would not be able to tolerate powers of 10 MW incident on the sample!). One such effect is that of induced optical activity[15] which might be important for the study of biological systems. It is doubtful whether the full implications of the use of such high power levels have been recognised. Such implications should be more fully investigated with help from experts in this area.

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SOME POSSIBLE USES OF A FREE-ELECTRON LASER IN THE SPECTROSCOPY OF GASES AND VAPOURS

by

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The proposed free-electron laser (FEL), codenamed FELIX, for the Daresbury site will, initially at least, provide pulsed radiation fully tunable between 75 and 150 μm, with the possibility of extending this range down to 50 μm. The peak power will be high (tens of Megawatts), but the spectral purity will not be particularly good, initially 0.1% (~ 0.2 cm^{-1}), with possibly an eventual improvement to 0.01% (~ 0.02 cm^{-1}). The accumulated expertise and the availability of specialised hardware at Daresbury will hopefully make the construction of the laser cheap, but there will inevitably be unexpected costs and in addition there will be all the costs of maintenance and support. It is unlikely that the facility will ever be offered cheaply - if full economic costing is adopted - so the questions to be asked are: (a) whether this laser will do things for the spectroscopist that he cannot get done any other way, and (b) how do the costs of alternative systems compare?

Gas-phase spectroscopists seek always to improve their sensitivity and their resolution. To a certain extent these two quantites are related, since the more gas one has, the higher is the pressure and the greater the pressure broadening. Typically this latter is about 10 MHz/torr, so at the pressures used, say a few torr, one will have a line-width of about 0.002 cm^{-1}. Doppler broadening depends on the molecular mass and on the frequency, but in the 40-70 μm region it will typically be about 0.001 cm^{-1}. One sees therefore that in conventional spectroscopy, resolution greater than about 0.002 cm^{-1} is unnecessary, because the lines under investigation will be broader than that. Fourier transform instruments of the present generation will do 0.1-0.01 cm^{-1}, and the newly-announced BOMEM instrument will do 0.001 cm^{-1}. On the coherent side of the house there are submillimetre carcinotrons, of the kind operated by Krupnov, which have currently been operated as high as 33 cm^{-1} (300 μm), and there are several kinds of tunable laser system which are available in several different regions of the infra-red. To be fair to FELIX, all these rival

systems are very costly and if SRC were to invest in a BOMEM, say, it would probably site it in a user-centre, but nevertheless one cannot see FELIX competing in the field of straightforward gas spectroscopy. The most exciting brand of non-straightforward spectroscopy is provided by Lamb-dip or saturation spectroscopy, in which it is posible to resolve features lying within the Doppler line-width. The power of FELIX is attractive here, but since the Doppler line-width is so small in comparison with the laser line-width it is dificult to see many cases where it could usefully be applied. The construction of a FEL would not be justified, therefore, for the purposes of what we might call conventional gas-phase spectroscopy.

There are, however, several non-conventional cases where a powerful tunable source would be very welcome; these would include those where the transition is inherently weak and/or where the concentration of absorbers is very small. One has

a) Spectroscopy of non-polar molecules such as CH_4, SiH_4, CF_4, SiF_4, C_2H_6, etc. These can absorb in the pure-rotational mode by virtue of higher electric moments, or else by virtue of centrifugal distortion or Coriolis interaction effects.

b) Spectroscopy of free-radicals and reaction intermediates - here one needs enormous path lengths, because the concentrations are so low, and since this means multiple reflections one needs lots of initial power to have enough left to measure at the end. The pulsed nature of the FELIX radiation could be very advantageous here, since the radicals or intermediates could be produced by flash-photolysis and the probing laser pulses could be synchronised with the production flashes.

c) Two-photon, or optical-optical double resonance, spectroscopy. This needs a very powerful laser to take the molecule up to a virtual state from which it can absorb another, usually a microwave, photon. Most of the work so far has been done with the powerful CO_2 laser or its isotopic and isoelectronic counterparts. These give out between them an enormous number of lines in a region where many molecules have rich absorption spectra. The information gleaned so far has been most fascinating; thus virtually everything we know about molecular colli-

sions has come from these studies, and it is reasonable to imagine that still more would be revealed if this kind of spectroscopy could be extended into other spectral regions.

d) Selective photochemistry: this has shown enormous potential for carrying out highly localised chemical changes in molecules and, even more intringuingly, for selectively dissociating isotopic species. The great puzzle at the moment is "how does it work?", since anharmonicity would he expected to lead to an initially resonant transition going out of resonance as it gets progressively more and more excited. The CO_2 laser at 10 μm has been widely used for this purpose and the remarkable fact seems to be that a molecule is capable of stepwise absorption of up to forty 10-μm photons before finally dissociating. The FEL could be used in two ways: firstly either alone - or more likely as a partner to another laser - as a primary driver and secondly as a diagnostic tool for investigating what is going on in this most remarkable process.

In addition to these more or less established fields, there are several very new areas where the power and tunability of a FEL could be very useful. Thus atmospheric studies "in the field" have been bedevilled by the lack of powerful enough tunable sources. Pollution measurements have also been hampered by the lack of tunable laser sources beyond 30 μm. Also the probing of the highly degenerate "gas" which is a thermonuclear plasma needs power - as much of it as you can get. The FEL might be attractive for Thomson scattering measurements on a new generation of machines such as JET, but there would clearly be a logistic problem here since the laser would have to be, in some degree at least, portable. Finally one can think of even more speculative areas. Burning "holes" through atmospheric absorption so that a subsequent probe beam can pass through, is one such. This clearly has miiitary possibiiities and it is not pure accident that the FEL development programmes in the USA and the USSR are firmly under military control.

DISCUSSION

1. COHERENCE

Dr. Chantry (NPL) asked what was meant by "coherence" in the context of this meeting. Spectroscopists usually meant the coherence length, equivalent to the inverse linewidth, whereas Dr. Pendry (Daresbury) used coherence for the number of photons in a given level. Would this latter type of coherence, the multiple boson occupancy with FELIX, be useful?

Dr. Pidgeon (Heriot-Watt) said that his group had looked at this type of coherence in three-level molecular systems, with Raman-type effects which could not be predicted by rate-equation theory. He agreed with Dr. Pendry that the multiple boson occupancy characteristic would be useful in studies of multiphoton processes.

2. PULSE STRUCTURE

Mr. Poole (Daresbury) decribed the pulse structure to be expected from FELIX, which would reflect that of the electron beam source. A macropulse of electrons would be available at intervals of 40 ms, although some adjustment of this period would be possible; clearly it would not be feasible to store the radiation over such a long period, so that FELIX would inevitably be a pulsed source.

Within each macropulse of several microseconds would be a train of electron bunches due to the radio frequency accelerating system, separated by ~ 2.5 ns (figure 1). The bunch length would be in the range 10-100 ps and would be variable, but a nominal 60 ps had been assumed in the FELIX proposal. Increasing the bunch length would reduce the peak electron current, leading to a lower FEL gain. The minimum acceptable bunch length was set by the basic operation of the FEL and would be an important topic of investigation on FELIX, but was likely to be at least 20 ps.

As each electron bunch traversed the interaction region it would generate a corresponding micropulse of amplified radiation and this would be reflected by the cavity mirrors. With the mirror separation a multiple of that between successive micropulses repeated amplification of a small

pulse train within the cavity would be achieved. Radiation would emerge from this cavity over much of the macropulse (> 1 μs) unless rapid mirror switching could be achieved. The space between micropulses might be variable but this would not be easy.

Dr. Chantry (NPL) pointed out that the width of one micropulse would lead to a linewidth ~ 0.5 cm^{-1}. Could the resolution be improved over this? Mr. Poole replied that standard laser techniques might be used to modify the linewidth of what was a multimode laser, particularly if some gain could be sacrificed. Dr. Pendry (Daresbury) thought that further monochromatisation would certainly be necessary for some applications, as this was an inherently broad source. Dr. Chantry commented that the long time-gap between micropulses could not be smoothed out by available monochromators, but extra pulses could be inserted by multiple reflection/Fabry-Perot techniques.

3. USING THE PULSE STRUCTURE

Dr. Pidgeon (Heriot-Watt) thought that one should either switch out one pulse and look at effects on a time-scale shorter than 60 ps, or look at effects on a much longer time-scale than 2.5 ns (the time between micropulses).

It was suggested by Dr. Lainé (Keele) that the micropulses could be stacked to build up very large electric fields, to investigate dynamic Stark effects and photodissociation. Dr. Nicholas (Oxford) pointed out that the pulse structure could be used for completely new types of experiments, for example using 1 pulse to excite a certain number of electrons into a semiconductor conduction band, and then using a second pulse to monitor decay processes.

4. OTHER POINTS

After a comparison of FELIX with the SRS, several people remarked that they would find the SRS a useful source of I.R. However Dr. Chantry (NPL) pointed out the characteristics of the two sources were really very different.

FELIX source would be useful - Dr. Chantry considered that it was a useful feature.

FIGURE CAPTION

Fig. 1 Temporal characteristics of radiation pulses from FELIX. The flat-top assumes saturation is achieved during the latter part of the macropulse.

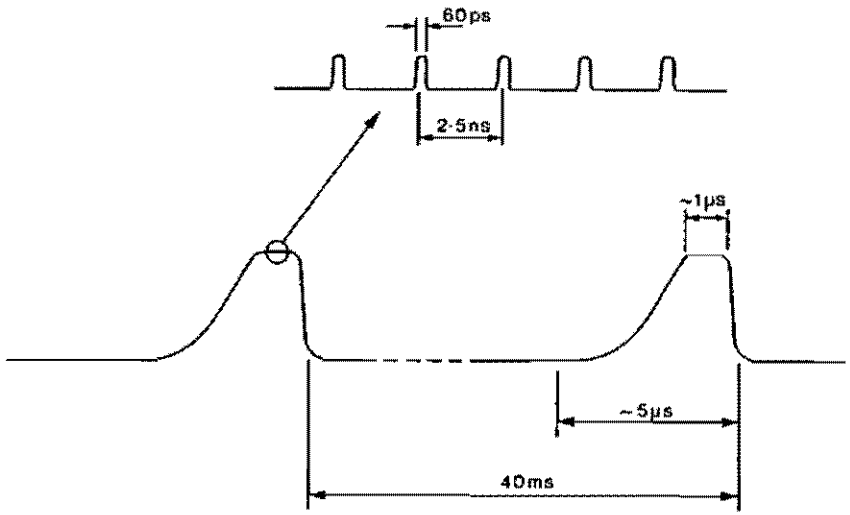

Fig. 1