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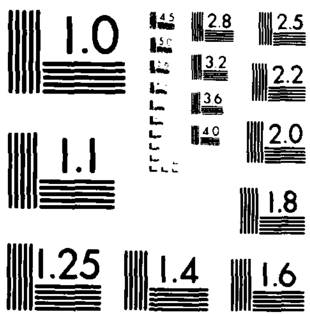

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FREE ELECTRON LASER PROJECT

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THE ~~USCB~~ UCSB FEL EXPERIMENTAL PROGRAM*

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The UCSB Free Electron Laser Experimental Program

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INTRODUCTION.

The University of California at Santa Barbara (UCSB) free electron laser (FEL) program was initiated in January of 1980 at the Quantum Institute to study the operation of electrostatic accelerator free electron lasers. A detailed discussion of the operation of these devices can be found elsewhere in this book under the title "Electrostatic Accelerator Free Electron Lasers" and also in reference [1].

The main goal in this paper is threefold: 1) to present a summary of the UCSB experimental FEL program to date, 2) to discuss future FEL device development objectives, and 3) to talk briefly about the future of applied research at UCSB.

There is presently in existence a large number of high energy electron accelerator machines that can be readily used as sources of electron beams suitable to demonstrate the basic operation of free electron lasers. This is the case, for example, with the superconducting electron accelerator at Stanford University where the first operation of the free electron laser was demonstrated in 1975, and where the potential operating characteristics of FEL's such as high power, high efficiency and broadband continuous tunability were clearly delineated. To realize all of the above predicted operating capabilities of free electron lasers it is, however, necessary to develop suitable electron beam sources.

Electrostatic accelerators appear to offer great promise for generating the electron beams needed by free electron lasers. Their conventional technology is well understood and there are good reasons to believe that this technology can be used with free electron lasers.

The UCSB FEL experimental program is based on the use of electrostatic accelerators in conjunction with the ideas developed by Elias [1] and Madey [2].

DESIGN OF THE UCSB FEL.

A conceptual layout of the UCSB FEL machine is illustrated in Figure 1. The major components of the system are:

Accelerator high pressure tank
HV generator
Electron gun
Electron accelerator column
FEL periodic magnet and optical resonator
Electron decelerator column
Electron collector
Ancilliary electron beam optics and control system

The accelerator shown in Figure 1 is being modified for FEL operations at the National Electrostatic Corporation factory and will be ready for initial electron beam tests sometime before the end of this year.

Accelerator High Pressure Tank. The high pressure tank contains the major components of the electron beam generation system. It is filled with high pressure sulfur hexafloride gas to electrically insulate the high voltage components. The tank stands 24 feet tall.

HV Generator. The high-voltage generator is not shown in Figure 1, but it is located inside the vertical accelerator steel tank shown. It consists of two charging chains (pelletrons) capable of delivering a total current of 500 microamperes to the high-voltage terminal. The high voltage terminal has been designed initially to withstand an initial maximum negative potential of 3 megavolts. With a larger high-pressure tank and larger high-voltage terminal, the maximum holding voltage of the device can be extended to 6 MV.

Electron Gun. The electrical design of the electron gun was carried out using the Herrmannsfeldt [2] computer code. It was designed to operate at a total electron current of 2 amperes at 60 kV. A schematic diagram of the gun is illustrated in Figure 2. The thermoionic cathode shown is 15 millimeters in diameter and operates at a current density of 1.13 Amp/cm^2. The intermediate electrode between the cathode and the anode is used to modulate the current in the gun. At +10 kV with respect to cathode potential, the modulating anode turns the gun on. At -2 kV the gun current is completely

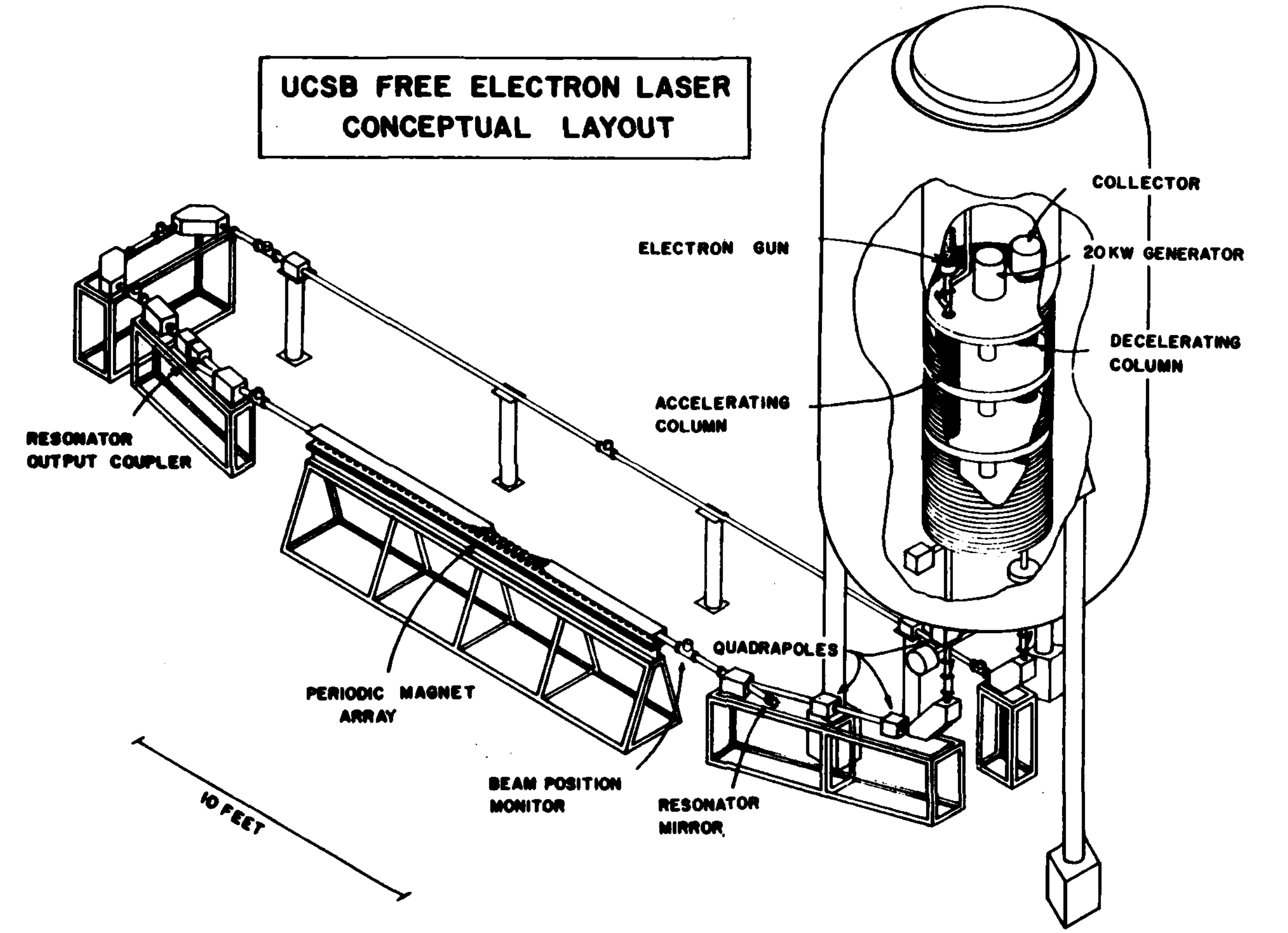


Figure 1. Conceptual layout of the UCSB free electron laser apparatus.

turned off. The electron beam trajectories inside the gun are all very nearly parallel to the gun axis. The emerging electron beam has an approximate radius of 6.2 mm and a diverging exit angle of 30 milliradians. In conjunction with its ancilliary electronics, the gun can produce continuously or on a pulsed basis an electron beam with a minimum pulse length of 100 microseconds.

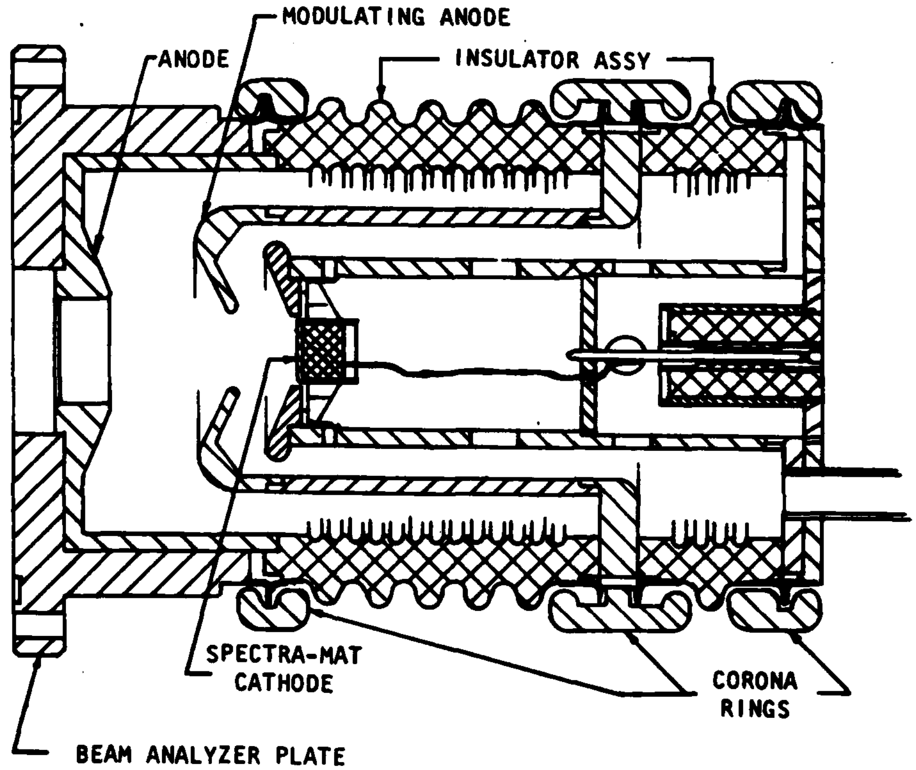


Figure 2. Electron gun design. a) cathode, b) modulating anode, c) anode.

Accelerating Column. The accelerating column was designed and constructed by National Electrostatic Corporation in Middleton, Wisconsin. It consists of 9 modules nearly 20 cm long, each producing a constant electric field on axis whose average magnitude is about 15 kV/cm. The longitudinal variations of the electric field along the axis gives rise to transverse electric fields which have a focusing effect on the electron beam. A program has been developed at UCSB to follow the trajectories of electrons inside the electrostatic accelerator. It includes the focusing effect of the accelerating column and the defocusing effect due to space charge forces. The following paraxial equations of motions were numerically integrated:

a) longitudinal equations of motion

$$\frac{d\gamma\beta_z}{dz} = -\frac{q}{mc^2\beta_z}\frac{d\Phi}{dz} \tag{1}$$

b) radial equations of motion

$$\frac{d}{dz}\left(\gamma\beta_z\frac{dR}{dz}\right) = \frac{q}{mc^2}\left[\frac{R\Phi''}{2\beta} + \frac{I\mu_o C}{2\pi R}\left(\frac{1}{\beta_z} - 1\right)\right]$$

where: (MKS)

γmc^2 = electron energy

I = electron beam current

β_z = longitudinal electron velocity

R = electron beam radius

Φ = electrostatic potential along the axis of accelerator

z = position along the axis of the accelerator

$\Phi'' = \frac{d^2\phi}{dz^2}$

Figure 3 shows the variations of electron beam radius with positions along the accelerator volumn. The electron beam shown has a maximum radius of 9 mm. The aperture of the accelerator column is 25mm diameter. For higher current beams it will be necessary to include additional magnetic focusing elements along the accelerator tube.

FEL Periodic Magnet. The FEL wiggler has not been constructed at this time. However, a permanent magnet wiggler will be built. Table 1 lists some of the possible wiggler designs being considered. Also, corresponding single-stage operating FEL characteristics are included.

Decelerating Column. A computer code has also been developed to analyze the trajectories of electrons inside the decelerating column shown in Figure 1. Electron decelerating trajectories have been generated for a variety of input kinetic energies to simulate the electron beam energy spread created by the FEL. The trajectories obtained did not change significantly with initial energy. The optimum trajectories appeared very much like the one shown in Figure 3, seen from right to left.

Electron Beam Collector. The electron beam collector was designed by R. Hechtel and its layout is shown in Figure 4. It is capable of collecting an electron beam having an energy spread of 10 kV and a mean energy of from 50 kV to 60 kV. The refocusing coil shown in the figure attaches directly to the end of the electron

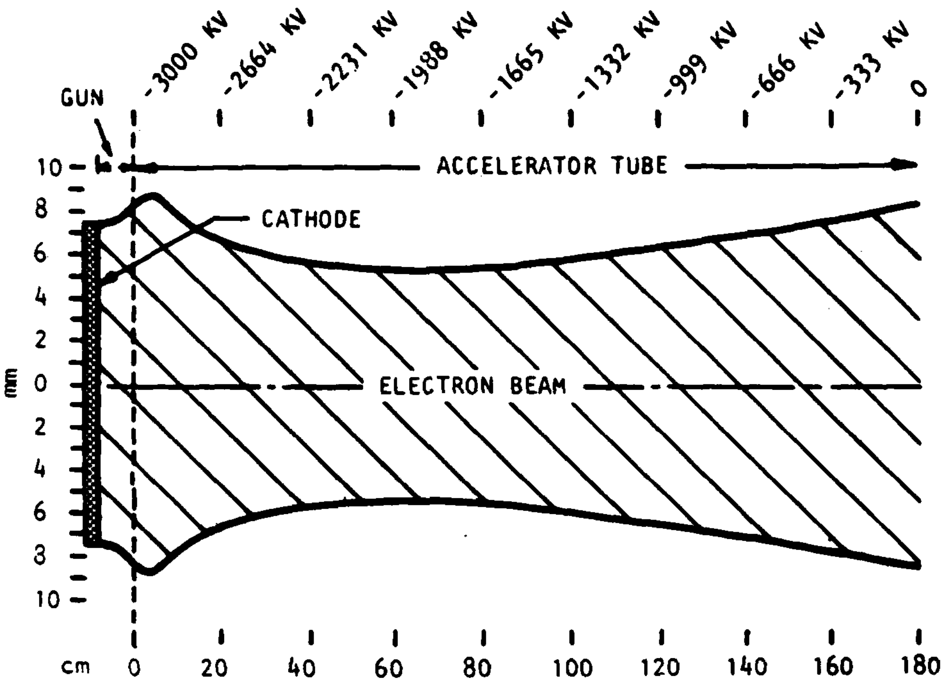
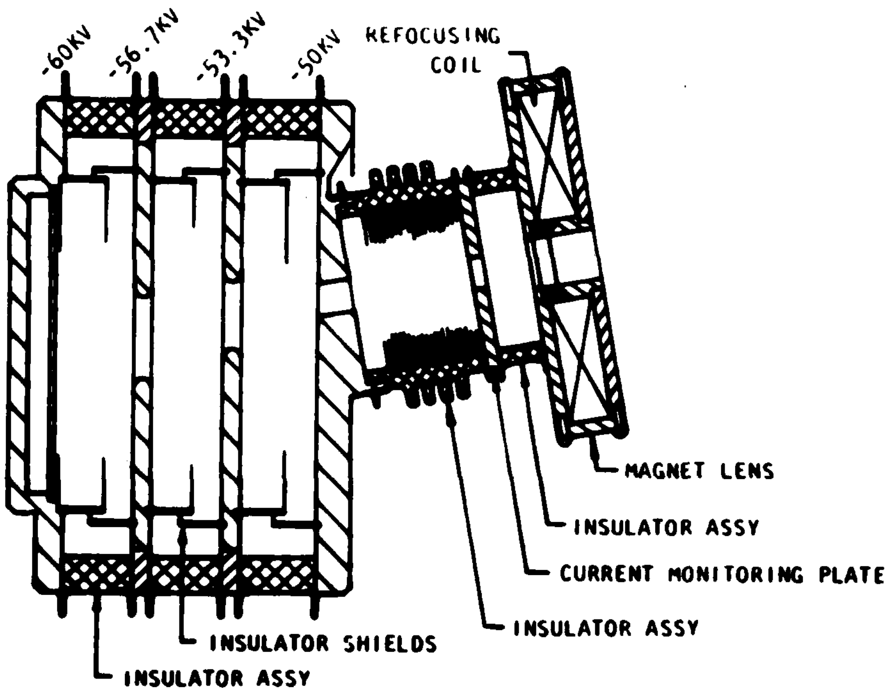


Figure 3: Electron beam radius as a function of position along the accelerating column. The vertical dashed line separates the gun from the accelerator column. The electron beam has cylindrical symmetry.

Table 1. Possible UCSB FEL design parameters. The optical mode assumed is a TEMoo circularly polarized. The current density in the interaction region is $16 A/cm^2$.

	I	II	III	IV
Mag. period (cm)	1	1.5	2	3
# of mag. periods	300	200	200	100
Elect. energy (MeV)	3	3	3	3
Elect. beam radius (mm)	2	2	2	2
$K_{MAX} = (e\ \lambda o\ B_{MAX}/2\pi mc)$	0.03	0.058	0.08	0.175
MAX B-field (Gauss)	328	413	428	624
Wavelength (μm)	106	153	205	360
Opt. beam waist radius (cm)	0.54	0.65	0.87	1.0
Small signal gain (Amp^{-1})	0.16	0.24	0.47	0.60
Power output (kWatts/amp)	5	7.5	7.5	15



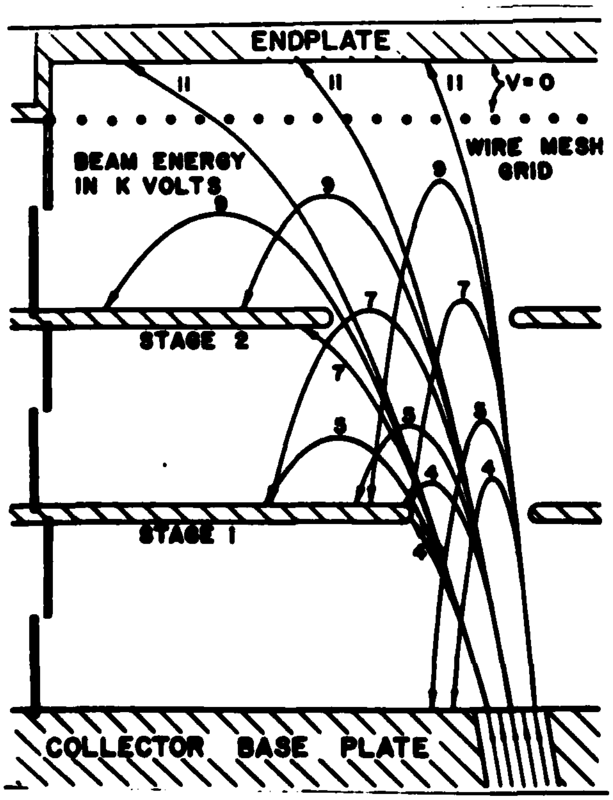


Figure 4: Electron beam collector. The collecting electrodes are labeled according to their electrical potential with respect to the H.V. accelerator terminal. (above)

Figure 5: Electron beam trajectories inside the electron beam collector. The numbers on the trajectories are associated with the electron's entrance energy. (to the left)

decelerating tube and focuses the electron beam into the entrance of the actual collector. The electric field inside the insulator assembly removes the mean energy of the electron beam. Thus, at the entrance to the collector assembly, the kinetic energy of the electron beam can have a minimum value of a few eV and a maximum value of 10 keV. There are altogether four charge collecting plates inside the collector. The trajectories of the electrons are shown in Figure 5. The reason why the electrons are collected on the back side of the collecting electrodes is to eliminate the possibility that secondary emitted electron will back stream into the decelerator section.

IMMEDIATE PROGRAM OBJECTIVES.

The primary objective of the UCSB project for the present year is to show that a 2 ampere electron beam can be produced and recovered using 3 MV electrostatic accelerator. Some of the electron beamline components needed to complete these abbreviated tests are shown in Figure 6. The electron beam emerging from the accelerating section is indicated by a vertical arrow at the top right-hand side of the illustration. The two 90° bending magnets return the beam upward into the decelerator section as shown in the figure. Initially the tests will be conducted using a pulsed electron beam. The pulse length of the beam will be later increased as the charge collection process becomes more efficient. Ideally, if only 500 μA of beam current is lost then the electron beam can circulate in a continuous manner because 500 μA is also the maximum current provided by the HV generator.

During the second year of research a complete single-stage free electron laser will be operated in the submillimeter region with one of the magnet designs shown in Table 1. Also, if the electron beam quality and intensity produced by the UCSB machine is as good as that required by two-stage FEL's then an attempt will be made to generate infrared or visible radiation using the two-stage FEL techniques discussed in reference [1].

FUTURE PROGRAM OBJECTIVES.

A natural continuation for the UCSB experimental program is to explore the possibility of using very high voltage electrostatic accelerators to generate efficient single-stage FEL operations with electron beam energy recovery. Electrostatic accelerators have been tested at 32 MV and there is some optimism that these machines can be designed to operate in the 50 MV range.

FUTURE APPLICATIONS RESEARCH.

The UCSB free electron laser will be able to provide scientists with a unique source of submillimeter radiation during its initial

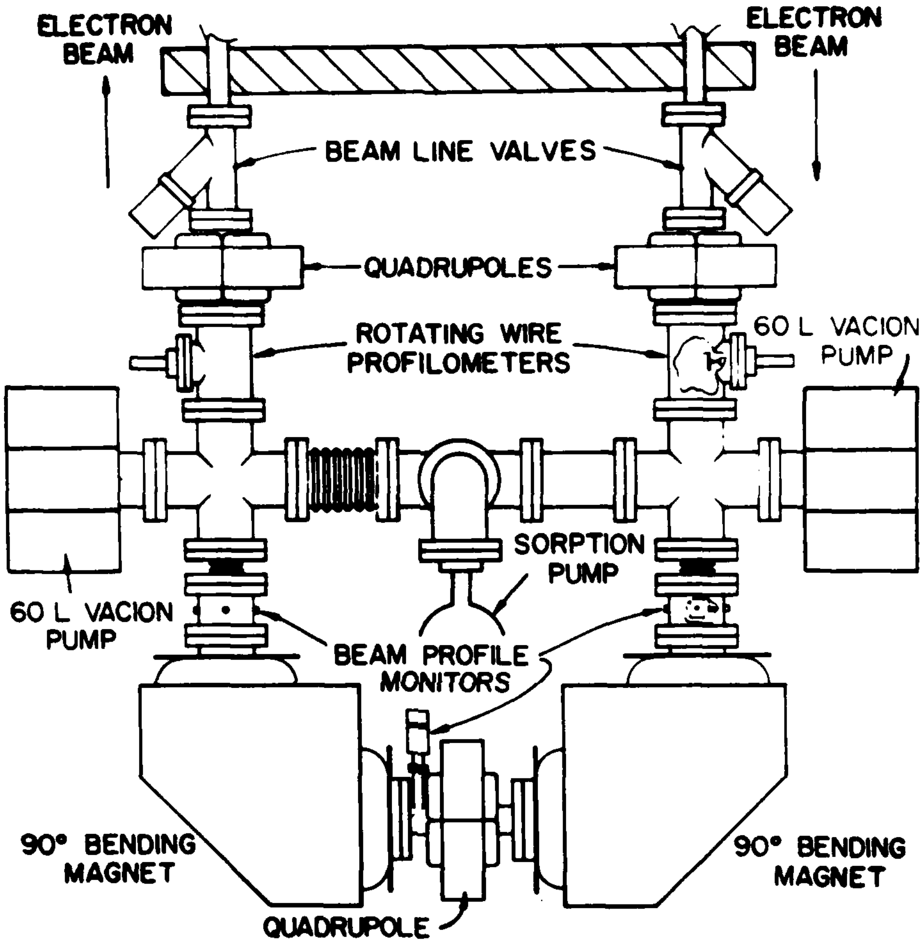


Figure 6. Electron beamline components for the first abbreviated UCSB tests. The accelerator tank is located above the figure.

stages of development. As is well known, there are no intense sources of coherent radiation in the submillimeter region. The availability of a strong monochromatic source of radiation in this region will allow experimenters to study, for example: 1) energy band gaps in superconductors, 2) rotational, torsional and orientational molecular states, 3) small electronic energy differences in semiconductors, and 4) localized heating of confined plasma. A review of the possible research applications of this device can be found in the report that evolved from the 1979 Trento workshop [3].

There is great interest at UCSB to established a User's Facility to provide scientists with the badly needed monochromatic source of FIR radiation. The UCSB machine is ideally suited to fill this need and a serious attempt is being made to procure the funds necessary to achieve this goal.

ACKNOWLEDGEMENTS.

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