National High Magnetic Field Laboratory

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TO: Members of the FEL Collaboration

First, my thanks to all for the insightful and spirited debate at our recent Free Electron Laser workshop. Your continued interest and enthusiasm is greatly appreciated. OK, I'll stop with the 'management-speak' now. Attached to this cover letter is a summary of the status of the MagLab FEL project, including the list of the current FEL specifications.

Below I list the consensus decisions (and a few of my unilateral decisions) intended to keep us moving on the same track at a rapid pace:

- **We must focus our design efforts exclusively on an RF Linac,** because the technology is more mature and the community of potential users is particularly broad. Quite a few of the desired specifications are given in this report. Thanks to all who helped draft it.
- **Research and testing of the Van de Graaf concepts should continue** as originally described in the proposal and at the workshop, but no detailed design work should be performed on the Van de Graaf source, because the technology is not yet well enough developed to be a major component of the MagLab FEL.
- **Erica Dow will be scheduling teleconferences** for late November and early January. I propose Monday, November 28 at 3pm EST and Monday, January 9 at 3pm EST. These teleconferences will be held monthly throughout the duration of this project. Feel free to add anyone I've overlooked to my draft list of teleconference attendees:

Greg Boebinger, Louis-Claude Brunel, Brian Fairhurst, Alex Lacerda, George Neil, Jerry Ramian, Mark Sherwin, John Singleton, Todd Smith, Hans van Tol and Gwyn Williams

Pressing issues

- **Postdocs should be hired as rapidly as practical**, with a particular eye to quality and diversity. J. Singleton hired Susan Cox to a postdoctoral position at the MagLab/LANL. M. Sherwin hired Susumu Takahashi to a position at UCSB. There is still one unfilled postdoctoral position at the MagLab/FSU, an interview is sdcheduled early December.
- **We need to develop the overall specifications of the building** required to house the FEL. This may be the most important milestone at this point, as Florida State University needs to have firm information by April 2006 to proceed with seeking funding.
- **I propose we fix the building specs at the regularly-scheduled MagLab User meeting on the Sunday before the beginning of the APS March Meeting.** We will advertise the particulars as soon as they are fixed, but pencil in 5pm – 7pm on Sunday, March 12, 2006…near the Oxford Instruments soiree, which immediately follows the MagLab meeting by tradition….our tradition, not theirs.

Sincerely,

Gregory S. Boebinger

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Conclusions from the MagLab FEL workshop at Gainesville FL, October 27, 2005.

1. Executive Summary: two distinct scientific communities

The workshop strongly reinforced a fact that was already visible in early drafts of the proposal. That is, there are two distinct scientific communities who desire FEL sources at National High Magnetic Field Laboratory (MagLab) in Tallahassee. Each is best served by radically different approaches to the Free Electron Laser (FEL) design.

The first, and larger, group require an FEL farm for (magneto)spectroscopy, time-resolved measurements, pump-probe experiments, imaging, microscopy and a wide range of other applications in physics, materials science, chemistry and biology. The deliberations of the workshop strongly suggested that this community is best served by an RF Linac FEL system, based on a variety of relatively mature and reliable technologies developed at FOM Nieuwegein (FELIX), Stanford and the Jefferson Laboratory.

The second community is those who desire a FEL for very high field pulsed magnetic resonance (EPR) applications. Long and sometimes heated debates about cavity design, a talk containing a wealth of potential scientific applications, and an informative lecture about pulse manipulation and error correction showed that this emergent application, while scientifically of great interest, is technologically far from mature. Interest in high-field pulsed EPR encompasses physics, chemistry, biosciences and quantum information processing, and the technique has the potential to produce some extremely exciting science. But as yet, it is difficult to say whether or not the pulsed EPR experiments with FELs are even feasible and our project demands a highly reliable FEL to successfully serve as a user facility from the outset.

In the text below, the requirements of these two user communities are considered separately. In Section 2, the workshop findings on the FEL system for spectroscopy, time-resolved measurements and pump-probe experiments will be described. **Section 2 contains our current set of specifications for the MagLab Free Electron Laser.**

Section 3 discusses the very different requirements of the pulsed magnetic resonance community, concluding that continued research under this project is desired, as described in the MagLab FEL proposal. The focus will be on developing the techniques and producing the first pulsed EPR results with an FEL. There will be no detailed design work on this FEL, as it would be premature. A separate detailed design proposal (i.e. separate from the presently funded MagLab FEL proposal) will await a more complete understanding of the possibilities.

2. The Case for an RF Linac Free Electron Laser.

2.1 Desiderata

Several speakers (Flavell, Reitze, Singleton, Basov, Hill, Davidson, Carr, Eyler, Greenbaum) described potential experiments that fall into the broad category of spectroscopy, time-resolved measurements and pump-probe experiments. These talks suggested many areas of science, encompassing physics, materials science, biosciences and chemistry, that would benefit from the provision of a FEL-type source at MagLab Tallahasee. In addition, Neil, Smith, Nguyen, van der Meer, Williams and Carr described design issues and experience gained in using FELs and other accelerator-based light sources for such studies. Several very general recommendations about the

desirable features of the FEL collection emerged from these talks and the ensuing discussions; these will now be listed.

a. Monochromatic (i.e. from FEL undulators) pulses are required, spanning the region from the far-infrared/THz (1 mm wavelength) to the near-infrared (1.5 microns).
b. A great experimental benefit would result from the simultaneous production of broad-band THz pulses. These would be used both for pump-probe experiments in conjunction with the pulses from the FEL undulators, and for THz spectroscopy.
c. The broad spectrum of user requirements suggests that it is essential to have varied and easily adjustable configurations of the pulses from the system. For some experiments with very low throughputs, tiny signals and the like, it is desirable from a statistical point of view to have a continuous stream of micropulses arriving at MHz repetition rates; for others (e.g. the FTICR molecular beam experiments, biophysics applications), it is preferable to have the ability to break the stream of micropulses into macropulses with variable length and repetition rate.
d. It is very desirable to be able to play off the spectral purity of the pulses from the FEL undulators with their time duration in a controllable fashion. For some experiments, picosecond time resolution is of the essence, for others, sharp lines are required.
e. Rapid tunability and/or swept frequency operation of the FEL undulators is desirable for some experiments; with the restricted length of the magnet shifts, it is good to be able to shift between wavelengths quickly. The examples of the Stanford machine, where 4 to 5 wavelengths per hour have been used in very careful spectroscopic studies, and FELIX, where some retuning is possible within the length of a macropulse, were cited.
f. Reliability and user friendliness were mentioned in many presentations; the ability to alter the FEL wavelength and monitor the beam parameters from a terminal in each experimental cell is very strongly desired. A number of speakers mentioned the possibility of users running overnight, essentially on their own, as is the practice at FELIX.
g. In order to optimize user utilization of the source, the ability to run FEL undulator experiments and broadband THz experiments independently was felt to be very beneficial.
h. The necessity to support the FEL system with other equipment (such as high-resolution FTIR spectrometers (for use with the broadband THz), Ti-sapphire lasers, OPAs and other light sources synchronized to the FEL pulses, microscopes etc.) was mentioned repeatedly.
i. There will be a need for zero and low-field user cells. It is inevitable that the resistive magnet stations are not always going to available for FEL experiments. The FEL should be equipped with a variety of “low-field” cells for microscopy, FTIR (e.g. for diamond-anvil high pressure studies using the broadband THz), technique development and so on. There should be one or two cells with superconducting magnets and a bio/nano/medicine station. It was stated that there could be a number of relatively economical FTICR stations running with permanent magnets.
j. The ability to have well-defined polarization states (circular, linear) was very desirable for some biophysics and magnetic measurements.

2.2 The Current MagLab FEL Specifications

Based on a judgment of the user power requirements, tunability etc., the FEL community present seemed to come to the following consensus (not, it must be added, without a little lively banter between the copper and superconducting linac communities).

i. An RF linac seemed to be the best choice for the above requirements, in that it offered the repetition rates and pulse flexibility that many users seemed to desire, plus the opportunity to produce broadband THz pulses with large intensities.
ii. The experiments demanding quasi-CW operation seemed to dictate a superconducting linac (cryomodule) approach, with the qualification that the pulse structure should be as flexible as possible. Given the MagLab's experience with the 45 T Hybrid, the use of superfluid Helium refrigeration in cooling these cavities should not present a problem.
iii. The wavelength range being suggested seems to point to a three undulator design, as proposed and simulated by George Neil in the draft design document. One undulator (THz/FIR) would be between the 10 MeV injection accelerator and the cryomodule, whilst the other two for MIR and NIR, would be beyond the cryomodule, operating at 10s of MeV.
iv. The extremes of quasi-CW power possible with energy recycling did not seem necessary. Moreover, the desire for rapid tuning would seem to make recycling less attractive. Therefore, based on a drop in average current of about a factor five from the draft proposal, the machine could be made non-recycling. However, it is desirable to design the machine and vault for possible future extension to energy recycling should higher powers become necessary.
v. The issues of reliability also seemed to suggest a thermionic, rather than laser-excited, gun to produce the bunches, provided that this can give the pulse control and timing control desired and produce the currents necessary for broadband THz generation (George Neil to consult with Todd Smith about this).
vi. Other design issues for the vault and machine are the future possibility of using Compton scattering to produce short pulses of high energy X rays. This will require careful design, as the X-rays are produced in a very "hot" area of the machine, and beam optics are challenging. The X rays do emerge highly collimated, and so the issue is to design a void behind the shielding along a line of sight (with a hole for a beam pipe already prepared) where a future X-ray station (including magnet) could be situated.

3. The Case for a Van de Graaf Free Electron Laser

There was considerable debate as to whether an RF linac-driven FEL could be made to produce the long pulses (nanoseconds) combined with high powers (kW) required for pulsed magnetic resonance applications. In addition, the method of constructing and coupling to the cavity in which the magnetic resonance occurs was the subject of considerable speculation. Talks by Ramian and Sherwin showed that a Van der Graaf driven FEL combined with pulse slicing was a possible candidate to at least provide the required powers and pulse lengths. However, contributions by Ardavan and Brunel suggested that the pulse slicing might have to be rather complex to achieve the sophistication necessary to compete in the burgeoning field of spin

manipulation. From all of this, it is clear that the FEL-driven magnetic resonance experiment does *not* represent mature technology. In contrast to the RF-linac FEL-driven pump-probe experiments, a considerable amount of development work remains to be done before one can be confident that the FEL magnetic resonance experiments will work in a worthwhile manner. Moreover, it is unlikely that such an experiment will constitute a user-friendly facility in the near future.

4. Conclusions: Design an RF Linac Free Electron Laser

The FEL effort will be split into two parts. The design of the RF-Linac, multiple-undulator machine for user experiments at Tallahassee will proceed, using the specifications listed in Section 2.2 of this document. This machine alone, with its building, user cells and associated equipment, will form the centerpiece of the construction phase of the MagLab FEL grant.

Independently of the RF Linac design work, development on FEL-driven magnetic resonance experiments will be undertaken at UC Santa Barbara using the existing FELs and pulse-slicing equipment there. At the time of the MagLab Renewal, formal support for this work at Santa Barbara will be considered for inclusion in the MagLab Renewal Proposal (e.g. funds for the provision of a large 20 T superconducting magnet plus staff at UC Santa Barbara). If and when the technology is proven for magnetic resonance experiments, it might well be transferred to the MagLab Tallahassee under a separate proposal. In view of this possibility, space for the possible eventual site of an electrostatic accelerator FEL should be included in the new FEL building at Tallahassee.

Appendix 1: Possible loan of the RAFEL free-electron laser

Dinh Nguyen of Los Alamos (LANL) suggested that the semi-portable RAFEL free-electron laser could be loaned to MagLab. This would enable experience of magneto-optics using FELs to be gained whilst the larger, multiple-undulator machine is under construction. Several of the FEL community thought that this was a very good idea, as experimental technique development could proceed in tandem with FEL construction. The RAFEL machine is in working order apart from the laser that drives the cathode. It could be made to produce wavelengths of between 3 and 30 microns, plus THz.

It is fairly clear that the LANL FEL group would prefer RAFEL to be used at MagLab Los Alamos; as the project would then be of greater interest to DoE management. However, at the same time, they acknowledge the undoubted superiority of quasistatic magnetic fields over pulsed fields for FEL magneto-optical experiments, especially for a machine like RAFEL with a rather low repetition rate for its macropulses. It is possible that some form of compromise agreement may be reached, whereby some experiments occur at LANL using a superconducting magnet. If they are successful, then perhaps RAFEL could be transferred to Tallahassee at a later date (say soon after the FEL building went up). Negotiations are under way.