Review of the "THz Coherent Light Source in Uppsala" as a new Swedish Research Facility"

Members of the Review Panel

Prof. Jerome Hastings
LCLS Directorate (SLAC), 2575 Sand Hill Rd, MS 102, Menlo Park, CA 94025, USA

Dr Marie-Emmanuelle Couprie
Synchrotron SOLEIL, Gif-sur-Yvettte, 91192, France

Prof. Sandra Biedron
Electrical and Computer Engineering, Advanced Beam Laboratory, Colorado State University, Foothills Campus, Fort Collins, CO 80523-1373, USA

General statement

The Stockholm-Uppsala Center for Free Electron Laser Research has developed a unique concept for the production and use of THz radiation with the long-term view of developing a user facility. Leveraging significant infrastructure that has already been established to support superconducting, radio-frequency accelerator module testing for the European Spallation Source enables the proposed facility. There is a clear scientific case that the proposed project addresses. However the proposed concept for the THz generation has not been experimentally demonstrated, so the development is clearly justified. If successful it is a proof of principle for the concept first proposed by T. Tanaka to produce high intensity isolated attosecond pulses in the hard X ray regime. It seems however premature to build a user facility solely focused on the use of the light from day 1, rather use of the facility for accelerator development and verification of performance through initial science experiments should be the first goal.

Comments on the specified issues

Terms of Reference

Make a general short assessment of the Science Case

The importance of THz sources in the study of condensed matter, chemistry and biology and biophysics has been well documented. [1,2,3] As a 'pump' source it is unique, for example the THz field can couple to a specific excitation in condensed systems and 'modify' the structure during the duration of the excitation. There are many examples in materials, surface chemistry and other fields that clearly show the potential. One example to highlight the importance of THz fields has been demonstrated, in several very beautiful studies in both strongly correlated electron superconductors and BCS systems where putative superconductivity has been observed

at temperatures considerably higher than in the absence of the THz field [4]. The unique potential to couple the THz source as a pump to unique photon probes spanning the spectral range from THz through to x-rays is to a large extent untapped. A source with the properties of the proposed facility coupled to x-ray free electron lasers, for example the EuXFEL in Hamburg and LCLS-II at SLAC, would be ideal.

Make a general assessment of the Conceptual Design and the main components of the proposed facility

The general components (electron source, accelerator, undulator, etc…) have been considered and are included in the conceptual design. What is required now is to down-select the specific components based on the system requirements. There are some components that may need development and integration based on the desired higher repetition rates in the long-term. (It is well-known that the demands of operational machines derived from research endeavors are ever-increasing in terms of repetition rate and average power.) The components should therefore be designed to be modular in order to upgrade portions, i.e. RF couplers, cathodes, etc. Start-to-end simulations will also have to be carried out in the next phase of the project development. A facility fully designed with the power-scalability in mind would push the research of the accelerator science and engineering as well as the user science capabilities.

Evaluate how the assumed performance of the facility will match the demands indicated in the Science Case

The proposed research concept for THz production satisfies the requirements to meet the needs for the scientific opportunities that are enumerated in the White Paper. Further, once the THz source has reached it's design goals a duplicate system could be built for MAX-IV. The combination with a MAX IV Beamline as an X-ray source rather than Compton backscattering locally is strongly encouraged. The MAX-IV source would allow both scattering and spectroscopy albeit not on the femtosecond but rather picosecond time scale. Further deployment of such a source at an FEL whether in Sweden or elsewhere is something for the future.

Comment on the essential performance parameters of the components of the source as discussed in the text and given in the tables. Are there any of these that would be difficult to reach or even seem to be unrealistic?

The proposed concept is novel and as a consequence presents some inherent risks and science and engineering challenges. The development to test Tanaka's concept in the THz regime is important as a first step toward the possibility of high intensity isolated attosecond pulses in the hard x-ray regime using X-ray Free Electron Lasers. The proposed concept is well adapted to

the infrastructure that exists at FREIA. Significant hardware and expertise already exists in beam science and engineering. It will in addition provide an ideal environment for students from the undergraduate to post-doctoral researchers. The challenges in the development at the facility in Uppsala will have significant impact on the science community, independent of the proposed soft X ray FEL facility assumed to be on the MAX-IV site.

Are there any critical components that you suggest should be more examined by e.g. simulations?

The consortium should perform start to end simulations of the complete system. Since the repetition rates demanded by the user are ever-increasing and since the research proposed to be performed at this facility will feed into user facilities, it would be prudent to increase the repetition rate of the RF as high as possible for day one operation and have a scalability plan in place to upgrade components (such as couplers) that require additional research before achieving cw or near cw operation. The team should leverage work already done in the field but push toward more compact, efficient designs while permitting scalability to high-average powers.

Are there alternatives for any of the components in the proposed facility, which you suggest should be investigated?

There is a limited selection of components available to achieve high repetition rates. The proposed concept of the system is sound, but the team needs to finalize the operational frequency and system components based on the beam dynamics. It would be good if there could a comparison amongst the several combinations of equipment choices to reach the same requirements. The down select needs to consider cost, footprint, operational reliability, and scalability to higher powers.

Comment on the value of adding to the facility an optional X-ray source as discussed in section 4.7

It will be important for users to be involved with the test of the THz source properties being generated at the test facility. This can be done with experiments using the THz pump-THz probe capability. In the long term the optimal use of this THz source will be coupling it with existing and planned free electron lasers operating over the full range of soft and hard x-rays. Development of the repetition rate and synchronization potential with these sources is of much higher priority than development of an in-house x-ray capability. For experiments with THz pump and x-ray probe the MAX-IV source offers an excellent opportunity permitting not only scattering but also spectroscopy. As well it is a route to develop the synchronization that will be required when such a source is coupled to an FEL.

Evaluate the uniqueness of the proposed THz light source

The proposed architecture of THz source is unique as that it is of the single-cycle type and the source can also deliver narrow band, depending upon the operational configuration. The development to test Tanaka's concept in the THz regime is important as a first step toward the possibility of high intensity isolated attosecond pulses in the hard x-ray regime using X-ray Free Electron Lasers.

In particular comment on the three statements in the Executive Summary

- ***it will be the first source designed specifically for pump-probe experiments***
- ***the broadband THz source will cover the range from 5 to 15 THz where the laser-based THz sources fail to work***
- ***The THz source will generate quasi-half-cycle pulses with field strength and repetition rate that are far beyond any existing or planned source***

The challenges for the development of THz sources are many: wavelength range, repetition rate, field strength and both single cycle and narrow band spectra. The proposed source is unique in that it addresses all of these challenges. It will cover the spectral range from 5-15 THz that is beyond the reach of current laser driven sources and further, it is capable of a much higher peak and average power. With focusing it will permit the community to reach 1 GeV/m or 1V/Angstrom for quasi-half cycle pulses so one can drive uni-directional displacements at surfaces for example in the study of catalytic systems. Finally, it can operate at repetition rates to match the most advanced x-ray FELs: the EuXFEL in Hamburg and LCLS-II in Stanford. The development will pave the way for new science opportunities and discoveries broadly in the material, chemical and biological sciences.

Recommendations

1. Begin the start to end simulations. This will focus the team on what's missing and the key areas for development.
2. Begin the development of an overall cost breakdown. This will also guide technical choices and feed back on hardware decisions even at this early stage.
3. Close collaboration between the source development and source utilization will be required for the ultimate success. Involving both the user and the project team in the development now will guide critical choices as the project evolves and highlight potential upgrades and future needs.
4. The developments of the gun laser and synchronization issues are paramount for the full potential of this THz source. It is prudent to involve the Lund Laser Center even at this early stage.
5. The scalability to high repetition rates is not only an exercise in beam physics and

experimental techniques. There is a significant amount of engineering involved. Similar to the laser development even at this point engagement of engineering departments at both Uppsala and Stockholm Universities is encouraged.

6. The facility should be established in a way so as to enable accelerator research for universities throughout Sweden.

References

[1] DOE/NSF/NIH (Department of Energy, National Science Foundation, and National Institutes of Health) Workshop on Opportunities in THz Science, http://www.sc.doe.gov/BES/reports/
files/THz_rpt.pdf, 2004

[2] https://www1.aps.anl.gov/accelerator-systems-division/meetings-workshops/thz-workshop

[3] https://portal.slac.stanford.edu/sites/conf_public/THz_2012_09/Pages/default.aspx

[4] See for example: M. Mitrano et al., Nature 530, 461–464, (2016)