Working Group VI Summary Report:
New Ideas Employing High-Power Lasers

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The objectives of this working group were to provide the "Future Light Source Community" information on:

- Electron-Laser interaction based sources
- Plasma based radiation sources and accelerators
- Present and future high-power laser technology

A summary of presentations, discussions and opinions is presented next. At the end of this report, a few references are given. The list is very far from being complete but is meant as a start for further exploring the various topics discussed in this working group.

The following scheduled presentations were made:

1. Dr. Todd Ditmire (LLNL):
   "High peak- and average-power ultrafast lasers and their application to femtosecond x-ray generation"
2. Dr. Igor Pogorelsky (BNL):
   "Gas Laser Technology for Future Laser Synchrotron Sources"
3. Dr. Tom Cowan (LLNL):
   "Short-pulse x-ray production by relativistic Thomson scattering"
4. Dr. Roman Tatchyn (SLAC):
   "Free-Electron Radiation Sources Based on High-Contrast Energy Modulation of Electron Beams"
5. Dr. Sterling Backus (U. Michigan):
   "Ultrafast Lasers and Laser-Based Coherent X-Ray Sources".
6. Dr. Eric Esarey (LBNL):
   "Ultrashort electron beam generation in laser plasma accelerators".
7. Prof. Don Umstadter (U. Michigan):
   "Ultrashort-duration x-rays from laser-plasmas".
8. Dr. Antonio Ting (NRL):
   "High Energy Electron Injection and Acceleration with Intense Short Pulse Lasers".

In addition, Prof. Keith Moffat (U. Chicago) presented some thoughts on source requirements and constraints from as user perspective, and Dr. Geoff Krafft presented recent results on high average power FEL operation at TJNAF.

Based on presentations and discussions during the workshop, a summarizing table of the performance of three different types of laser systems has been made. The emphasis is on listing performance parameters of solid state, FEL and gas based lasers, relevant to the development of a future fourth generation light source . Two types of solid state lasers capable of producing peak power in the multi-terawatt range are described: Nd:glass and Ti:sapphire lasers [1]. The main development for these lasers is towards higher average power levels: from the 10 W to the > 100 W level. An infrared FEL has recently produced 1 kW average power but with peak power on the order of 0.1 GW [2]. A terawatt class, short pulse CO_2 based gas laser is under development at the Advanced Test Facility at BNL [3].

	Nd:glass	Ti:sapphire	FEL	ATF-CO_2
Wavelength	1053 nm	800 nm	3-6 micron	10.6 micron
Energy/pulse	< 500 J	<10 J [(1)] 25 mJ @1-10 kHz	30 μJ	1 J 30 J
Pulse width	> 400 fs	15 – 100 fs	> 370 fs	150 ps 10 ps
Rep. Rate	< 1 shot/hr	10 Hz	37.5 MHz	0.03 Hz 0.1 Hz
P_{peak}[TW]	< 1 PW	< 100 TW <0.5 TW	0.1 GW	6 GW 3 TW
P_{avg} [W]	NA	10 W 15 W	1 kW	NA
Synch. to RF	1.3 ps	1 ps	< 1 ps	1 ps

Table 1: Far from being complete, this table lists parameters with relevance to the potential use of four different laser systems (solid state, FEL and CO_2) for a fourth generation light sources. The best current day performances are listed for the various systems as reported at the workshop. A Nd:glass system at LLNL has the record for highest peak power (PW). However the average power is very low. Ti:sapphire systems with high peak power (1 – 10 TW), short pulses (15 – 100 fs) and average power nominally around 10 W are in operation at many research laboratories around the world. Peak powers as high as PW are expected for low repetition rate systems and 10 TW is expected for high repetition rate systems (1 – 200 kHz) in the next 5 years of development. An infrared FEL based laser at Thomas Jefferson National Laboratory (column 4) has achieved the highest average power (1 kW). However the peak power is low. The ATF at BNL is developing a TW-class CO_2 based laser system. Current and future performance parameters are listed in column 5.

A summary of the performance (brightness vs. photon energy) of various laser based x-ray sources is presented in Fig. 1. Current methods for laser high harmonic generation are expected to produce bright, compact (table top) sources with photon energies up to the few 100 eV's [4]. X-ray lasers can produce higher brightness, but due to refraction and plasma effects, photon energies are limited to again the few 100 eV's [5]. X-ray lasers are useful for microscopy applications. Laser/solid target sources produce higher energy photons but peak brightness is probably not sufficient for x-ray diffraction experiments for the 10's of keV[6]. Thomson scattering sources are being developed to produce tunable, short duration hard x-ray pulses at several labs [7]. Sufficient brightness to allow diffraction and EXAFS experiments is expected for the Thomson scattering based sources. PW laser systems are capable of providing x-rays and γ-rays.

Although summarizing source performance using a single number (e.g. peak brightness) can be useful for some comparisons, proper evaluation must be made based on the type of experiment and its requirements and on the ease of implementation and available infrastructure. Laser based sources offer unique properties. For example, Thomson scattering based sources can produce tunable ultra-short x-ray pulses using relatively low energy electron beams, rapid polarization and wavelength control is possible through the laser polarization and wavelength chirp, respectively. Sources based on laser-gas or laser-solid interaction are table top size and only require the availability of a high power laser system, which is becoming commonplace. Laser based slicing offers the possibility to produce ultra-short x-ray pulses using existing storage ring facilities [8]. Laser wakefield acceleration methods are currently being pursued at various laboratories around the world and offer the possibility of an all-optical accelerator [9]. In these schemes, high power laser pulses are used to produce large amplitude plasma wake propagating with a phase velocity close to the speed of light. Experiments to date have shown the trapping and acceleration of plasma electrons by these plasma wakes. Most of the accelerated electrons had energies in the few MeV energy range but a detectable number of electrons were accelerated up to 100 MeV, indicating acceleration gradients as high as 100 GV/m. Although the energy spread in these experiments is 100 % , various schemes have been proposed that promise reduction of this spread to the %-level through a laser triggered injection process. Low divergence beams have been measured containing 10^9 electrons. The use of ultra-short laser pulses automatically leads to ultra-short electron bunches (1 – 10 fs) and peak currents on the order of kA are expected.

It should be noted that some of these laser-based source concepts are complementary to, and could be a part of existing or future accelerator based light sources. For example, the pioneering experiments on Thomson scattering were performed on the ALS injector, and the high intensity source under construction at LLNL involves a linac configuration very similar to the injector proposed for SASE-FEL sources. The x-ray characteristics pulse characteristics that one may be able to attain include high peak flux with a finite bandwidth in a very short pulse (as high 10^9 photons in ~10% BW in <100 fs, or >10^{10} in ~1 ps). This type of source could be useful in the near term to help develop the time-resolved pump-probe techniques and to explore their applicability to some types of problems which would be of interest in helping to establish the scientific case for the next generation light sources. Examples of initial exploratory experiments for which these x-ray parameters might be useful could include Laue scattering measurements for structural biology, EXAFS measurements in chemical systems, or time-resolved Bragg scattering for solid state experiments.

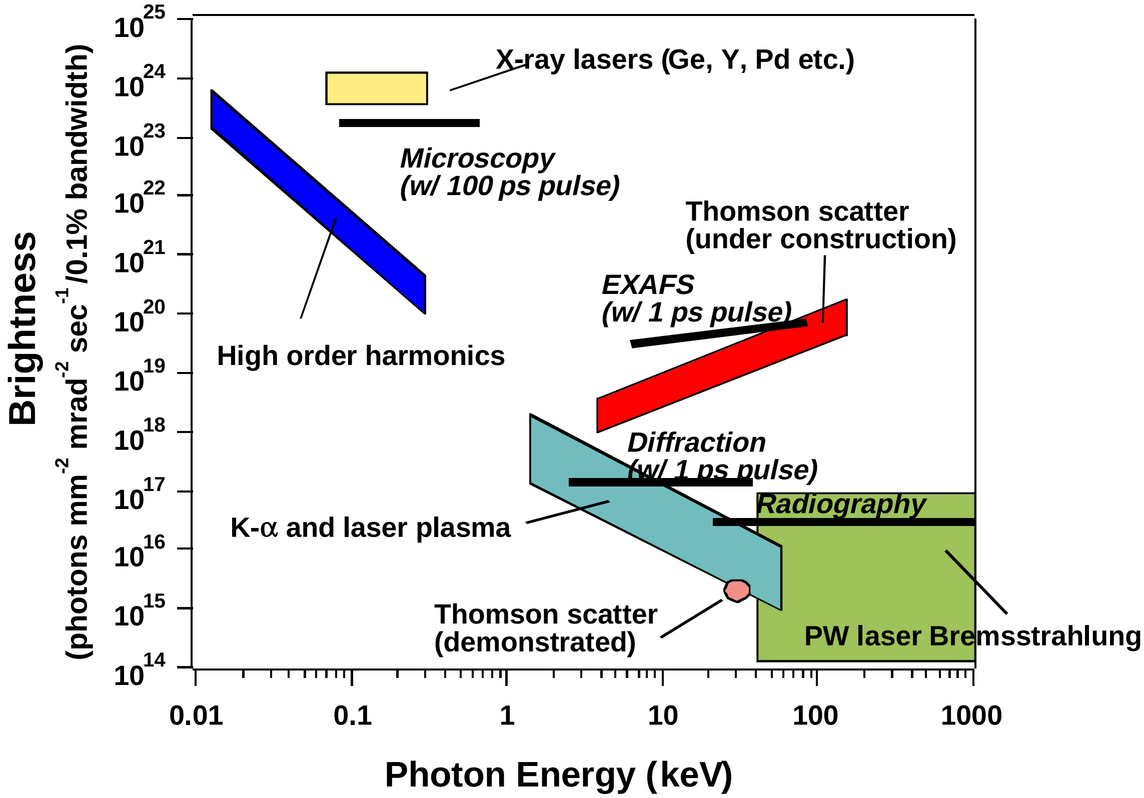

Figure 1: Peak brightness vs. photon energy for various laser based x-ray sources. (Courtesy of Tom Cowan and Todd Ditmire (LLNL)).

Laser technology continues to advance at a rapid pace, and as noted in the charge to the Workshop, much of the cutting edge time-resolved spectroscopy is being done by this community. We recommend that relatively inexpensive, near-term laser based and laser-electron x-ray sources be given further attention as test beds for performing exploratory experiments to build the scientific case for a future light source.

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