

Lasers and Laser Applications

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The year 2015 was declared by the United Nations to be the International Year of Light and light-based technologies. The opening ceremonies not only celebrated the present but also acknowledged the past and hinted at what was in store for the future. In the modern world, 50 years after the demonstration of the laser, light impacts everything we do from communicating, to manufacturing, to health care. This is not surprising, because 50 to 100 years is the adoption cycle of a new technology for widespread use by society. Just think for a moment about railroads, electrification, air transportation, the national highway system, electromagnetic communication from the radio, television, and the Internet.

So what about the future of lasers and laser technology? We are now six years into the x-ray-laser age, and x-ray lasers based on linear accelerators are being constructed around the world. What will the characteristics and applications of the x-ray laser be 50 years from now? We can expect that, like the radio and the laser, in 50 years the x-ray laser will be integrated into wide use by society in applications such as precision medical imaging, protein structure determination, and coherent transmission of information at rates 10^5 times higher than with visible light. We can also expect advances in x-ray power that will allow for controlling matter at the high densities suitable for small-scale inertial fusion power generation. The field of x-ray nonlinear interactions will be extended from x-ray to gamma ray frequencies suitable for probing nuclear energy levels and for pumping gamma ray lasers.

Laser-driven accelerators will open up a host of applications in the future. Going from Klystrons to laser-driven accelerators reduces physical device scale by 5 orders of magnitude. Accelerators could even be made as all-solid-state devices on a wafer scale. For example, a few-centimeter-long accelerator will generate MeV-energy electrons at a mode-locked laser repetition rate of 100 MHz and would be ideal for treating patients. Such an accelerator, if fitted into a catheter, would revolutionize radiation medicine. This same technology could enable an all-solid-state scanning electron microscope of centimeter length that is driven by compact fiber lasers.

A 1-m laser accelerator with 1 GeV electrons of 10-attosec duration at a 100-MHz repetition rate is ideal for driving a free-electron laser (FEL) that operates at x-ray frequencies. The 100-MHz repetition rate allows the consideration of an FEL laser with a resonator to match the 100-MHz period. Using, for example, diamond mirrors, this sync-pumped FEL opens the door to upconverting a comb of modes from the visible to x-ray frequencies. This in turn leads to opportunities for precision clocks, precision spectroscopy, and attosecond-timing resolution measurements in the hard-x-ray region, as well as field strengths adequate to ionize the vacuum. Imagine the vacuum as the ideal nonlinear medium for future experiments.

High-average-power lasers have opened the door to new applications. As the power level increases in the future to approach and exceed the 1-MW level, new and surprising applications are enabled. For example, a laser of 15-MW average power operating at 100 pulses per second, located on the ground, will enable the launching of satellites into low earth orbit, each with a mass of greater than one ton. A laser of 35-MW average power operating at a 15-Hz repetition rate is ideal for driving a laser inertial fusion power plant with a 1-GW electrical output. When that happens, laser energy will become the carbon-free energy of choice: stars burning under control on the surface of the earth.

In the future, if laser propulsion were used to launch hundreds of 2-m-diameter telescopes and the telescopes were directed into formation as a constellation of satellites, then optical

telescopes of 1000-m diameter and greater would be possible. How would these mirrors be aligned? Again the laser offers the solution through the use of precision clocks and precision interferometry to locate each 2-m mirror to better than 1/100 of an optical wave in space-time. Such a telescope array would enable detailed studies of exoplanets using precision spectroscopy based on laser frequency combs.

It seems appropriate that in 2060, 100 years after the demonstration of the laser, the amazing laser will continue to serve society across multiple dimensions from energy to manufacturing to health and the environment.