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Summary of the 2011 Dielectric Laser Accelerator Workshop

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ABSTRACT

The first ICFA Mini-Workshop on dielectric laser accelerators (DLA) was held on September 15–16, 2011 at SLAC National Accelerator Laboratory. We present the results of the workshop, and discuss the main conclusions of the Accelerator Applications, Photonics, and Laser Technologies working groups. Over 50 participants from four countries participated, discussing the state of the art in photonic structures, laser science, and nanofabrication as it pertains to laser-driven particle acceleration in dielectric structures. Applications of this new and promising acceleration concept to discovery science and industrial, medical, and basic energy sciences were explored. The DLA community is presently focused on making demonstrations of high gradient acceleration and a compatible atto-second injector source, two critical steps towards realizing the potential of this technology.

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1. Introduction

Dielectric laser acceleration (DLA) refers to the use of optical to infrared (IR) lasers to drive high-gradient particle acceleration inside of a vacuum channel in a dielectric structure. DLA is a promising and rapidly progressing field of research and development in particle accelerator technology. The high breakdown threshold of dielectric materials at optical frequencies, relative to metals in the RF regime, makes possible significant improvements in accelerating gradient. Efficient, inexpensive, and commercially available lasers spanning a widening wavelength range can enable cost-effective accelerator systems for a variety of applications. Furthermore, the amenability of DLA structures to industrial fabrication techniques makes inexpensive commercialized mass-production a possibility. The field of DLA has achieved remarkable progress in recent years, with detailed design studies of photonic crystal and planar structures [1–4], experimental demonstration of net acceleration, and advances in fabrication techniques.

To assess the state of the field and discuss future directions, the first Dielectric Laser Accelerator Workshop was held on September 15–16, 2011, at SLAC National Accelerator Laboratory. The workshop consisted of three working groups: (1) Accelerator Applications, (2) Photonic Structures and Optical Materials, and (3) Laser Technology Requirements. While the Photonics and Laser Technology working groups were tasked with discussing particular structures and laser systems, the Accelerator Applications group was tasked with discussing how DLA technology might be applied to various types of accelerators. The applications of particle accelerators are highly varied, from small systems for medical use, where compactness and cost are of paramount concern, to high-energy colliders where accelerating gradient and power efficiency are key. The following charge was put to the working groups:

1. Identify the state-of-the-art in each field as it pertains to laser-driven particle acceleration.
2. Outline general parameters for potential industrial, medical, compact light source, and linear collider applications.
   a. Identify interface requirements between the accelerator, photonic devices, and laser systems in each case.
   b. Identify critical parameters that make or break performance in each case.
3. Identify key areas needing R&D, and sketch an R&D roadmap in each of the three subject areas.
4. Increase awareness of efforts in adjacent disciplines, identify synergies, and grow collaborations between the accelerator physics, photonics, and laser R&D communities.

2. Accelerator applications

Although DLA is a relatively new area of scientific research, the field has advanced along multiple fronts in the last few years.

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Recent work has yielded new structure designs, laser technology, injection mechanisms, fabrication techniques, experimental diagnostics, and simulation tools. There are now three distinct types of DLA structures that have been explored in detail: planar structures, which include gratings [1] and/or dielectric stacks [2]; photonic crystal fibers [3]; and three-dimensional photonic crystal structures fabricated using integrated circuit technology [4]. Efficient, short pulse lasers now exist in wavelengths spanning nearly the entire 1–2 μm range, and efforts are underway to reach longer wavelengths using parametric techniques.

The near-term goal common to virtually all projects in the DLA community is the demonstration of high accelerating gradient. In this context, high gradient means well beyond the 30–100 MV/m regime of current widely used acceleration techniques. By contrast, dielectrics have been demonstrated [5,6] to withstand electric field stresses well in excess of 1 GV/m, which is an order of magnitude higher than the breakdown limits for traditional microwave cavities. Developing accelerator structures that effectively exploit this capability will require laser systems, dielectric materials, structure topologies, and power couplers that together provide high gradient and damage threshold, while minimizing field enhancement. Several groups are experimentally exploring microtip-based electron emitters for direct injection of optically bunched beams, and we expect demonstrations of acceleration in DLA structures to occur in the 1-year time frame. It therefore makes sense to consider how current technology might scale or be integrated to achieve operational accelerator systems suitable for various types of applications. To this end, we discuss below applications for DLA in three main areas: discovery science, basic energy science, and medical science.

2.1. High-energy collider

Due to the growing cost and size of high-energy physics (HEP) facilities based on traditional RF accelerator technology, it is clear that revolutionary new accelerator concepts are needed to continue into the 10 TeV center-of-mass energy range and beyond. DLA is a particularly promising advanced concept for a future HEP collider. Example parameters for a 10 TeV collider are provided in Table 1. The three different examples ("Woodpile", "Fiber", "Grating") correspond to three different structure types under development, which are discussed in Section 3 and shown in Fig. 1. These are compared with international linear collider ("ILC") parameters scaled to 10 TeV to provide a baseline comparison against traditional RF technology. The key parameters for a DLA-based collider are gradient, wall-plug efficiency, and luminosity. Gradient is clearly critical to keep the accelerator length, and hence civil construction cost, reasonable. Since laser technology has made great strides in wall-plug-to-optical efficiency, the accelerator design requires maximizing optical-to-beam efficiency. The DLA beam power is generated by accelerating low-charge, low-emittance bunches at high repetition rate. In Table 1, the repetition rate is adjusted for the structures in order to roughly match the luminosity while keeping total wall-plug power manageable. The small beam emittances allow these bunches to be focused to the very small spot sizes needed to achieve the desired luminosity, the high repetition rates allow feedback to stabilize the beams to collide at the interaction point, and the very low bunch charge reduces the beamstrahlung loss. Indeed, at multi-TeV collider energies, a high repetition rate small bunch charge accelerator may be the only route that is sufficiently free of beamstrahlung backgrounds to be used for high energy physics.

Table 1
Strawman parameters for a 10 TeV linear collider for three DLA structures.

Parameter	*Units*	*"ILC"*	*Woodpile*	*Fiber*	*Grating*
*E*_cms	GeV	10,000	10,000	10,000	10,000
Bunch charge	e	3.0E+10	1.8E+04	3.8E+04	1.0E+04
# Bunches/train	#	2820	136	159	375
Train repetition rate	MHz	5.0E−06	25	5	10
Macro bunch length	ps	2820	1.00	0.50	0.33
Design wavelength	μm	230,609.58	1.55	1.89	0.80
Invariant emittances	μm	10/0.04	1e−04/1e−04	1e−04/1e−04	1e−04/1e−04
I.P. spot size	nm	158/1	0.06/0.06	0.06/0.06	0.06/0.06
Beamstrahlung *E*-loss	%	16.3	2.4	5.4	3.8
Enhanced luminosity	**/cm^2/s**	**1.23E+36**	**2.04E+36**	**4.09E+36**	**2.82E+36**
Beam power	MW	338.8	49.0	24.2	30.0
Wall-plug power	MW	1040.0	490.2	242.0	300.4
Gradient	MeV/m	30	197	400	830
Total linac length	km	333.3	50.8	25.0	12.0

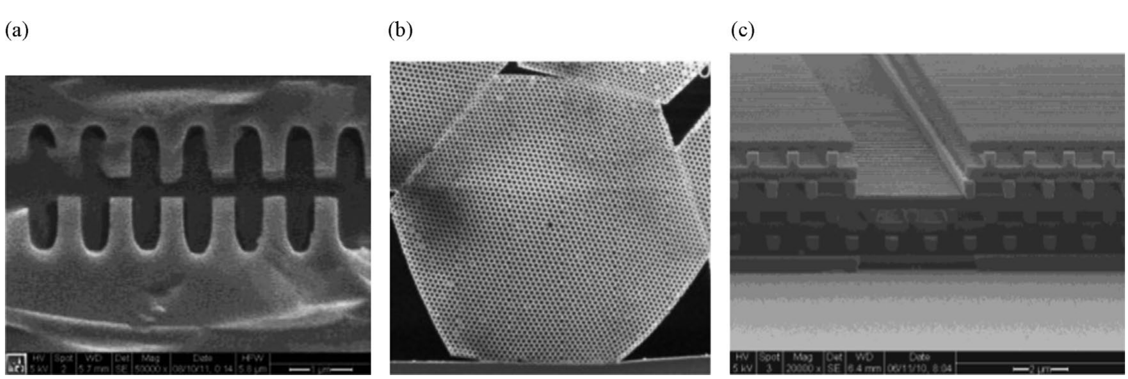

Fig. 1. Recently constructed prototypes of (a) the 1D dual grating accelerator structure with 800 nm period. (Stanford University), (b) the 2D photonic capillary wafer accelerator structure with transverse size about 700 μm (Incom, Inc.). (c) Nine-layer half structure of the 3D photonic woodpile with rectangular defect region where the particle beam traverses into the page (Stanford University).