Available online at www.sciencedirect.com

ScienceDirect

Physics Procedia 52 (2014) 68 – 74

Physics Procedia

Physics and Applications of High Brightness Beams Workshop, HBEB 2013

Mid-Infrared Laser System Development for Dielectric Laser Accelerators

Igor Jovanovic*, Guibao Xu, Scott Wandel

The Pennsylvania State University, 233 Reber Building, University Park, PA 16802, USA

Abstract

Laser-driven particle accelerators based on dielectric laser acceleration are under development and exhibit unique and challenging pump requirements. Operation in the mid-infrared (5 μm) range with short pulses (<1 ps FWHM), high pulse energy (>500 μJ) and good beam quality is required. We present our progress on the design and development of a novel two-stage source of mid-infrared pulses for this application, which is based on optical parametric amplification. Beta barium borate and zinc germanium phosphide crystals are used, and are pumped by a Ti:sapphire ultrashort laser and seeded by self-phase modulation and parametric generation-based sources.

Peer-review under responsibility of the scientific committee of HBEB 2013

Keywords:

1. Introduction

Laser-driven particle acceleration represents an increasingly attractive approach for production of high brightness electron beams and advanced light sources. The development of laser-driven acceleration methods could result in a considerable increase in acceleration gradient and/or commensurate reduction of system size, complexity, and cost. Promising techniques based on laser-beam interactions could also improve the performance of bright light sources such as free electron lasers and their applications. Laser requirements for these applications are frequently unique and stringent, requiring a dedicated effort to advance and adapt the current and develop new

* Corresponding author. Tel. +1-814-867-4329
E-mail address: ijovanovic@psu.edu

Peer-review under responsibility of the scientific committee of HBEB 2013
doi:10.1016/j.phpro.2014.06.011

laser technologies. The major trends in research and development of lasers for particle accelerators and advanced light sources include the efforts to increase the repetition rate and efficiency of high peak power systems by use of technologies such as a fiber laser coherent addition (phasing), increasing the peak power available from individual fibers, developing new materials and cooling approaches for bulk lasers, and developing laser hosts and nonlinear optical approaches to realize high-power coherent sources in the mid-infrared regime. Here we focus on the latter goal as a means to provide pump sources for novel dielectric laser accelerator schemes (Naranjo et al, 2012).

A significant development of mid-IR laser sources, covering the wavelength range from 2 μm to 25 μm, has occurred since 1980s due to their extensive application in the areas such as molecular fingerprinting (Diddams et al., 2006*)*, trace gas detection (Thorpe et al., 2008), frequency combs (Schliesser et al., 2012), and laser spectroscopy (Tittel et al, 2003). Production of mid-IR pulses remains technically challenging, especially if high-energy and ultrashort pulses are sought. Simultaneously, the rapid development of microfabrication techniques for dielectric structures has led to increasing interest in laser-driven particle acceleration in such photonic structures (Rosenzweig et al., 1995, Plettner et al., 2008). By using a mid-IR laser source, multiphoton ionization leading to the breakdown of the dielectric structure can be largely mitigated. Long laser wavelength also allows relaxation of all structure dimensions, and permits larger structure apertures and stored energies, thus allowing greater pump energies to be used to pump the structure.

2. Requirements, Technical Approach, and System Design

Our proposed dielectric-based laser accelerator requires a mid-IR pulsed laser source which operates at 5 μm wavelength with 500 μJ of pulse energy and 1 ps FWHM pulse duration. Laser gain media for direct production of mid-IR high-energy laser pulses do not exist, which requires that various nonlinear frequency conversion technologies be considered. Optical parametric generation (OPG)/optical parametric amplification (OPA) is an ideal approach for this application, capable of extending the wavelength to the mid-IR region through frequency down-conversion of the established and widely available high-energy short-pulse lasers, such as the Ti:sapphire (Ti:Sa) laser.

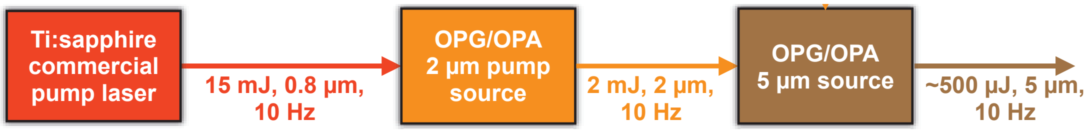

Figure 1. Overview of the technical approach for the two-step OPA system for 5 μm pulse production.

A schematic overview of our OPA system is presented in Fig. 1. The 5 μm mid-IR laser source is realized by using an OPG/OPA system based on parametric down conversion. Among a few candidates for nonlinear crystals which could be utilized in mid-IR wavelength region (Nikogosyan 2005), $ZnGeP_2$ crystal has been chosen for our 5 μm source due to its excellent transparency in the mid-IR wavelength region, high nonlinearity, and commercial availability of high optical quality crystals. Femtosecond OPG operation in the mid-IR wavelength region has been demonstrated with $ZnGeP_2$ (Petrov et al., 1999). With suitable anti-reflection (AR) coating for both the pump and the output mid-IR wavelengths, the quantum conversion efficiency for ultrashort pump pulses could be expected to be >40% due to the extremely high damage threshold (>100 GW/cm^2) of the crystal and the relatively favorable group velocity matching.

From the perspective of portability and robustness of the OPG/OPA system, as well as the compactness of design and its final integration with the dielectric particle accelerator, the optimal solution for the pump source for the 5 μm OPG/OPA system is a Tm/Ho/Cr-doped high-energy solid-state laser that operates around 2 μm. Because of the limited performance and maturity of Tm/Ho/Cr-laser technologies, however, alternative approach to realize high-energy 2-μm pump source has to be considered. In our design, a surrogate OPA source pumped by a mature Ti:Sa laser is employed. This approach is mid-IR-pump-compatible since the 2-μm nonlinear pump source can be directly replaced by a Tm/Ho/Cr-based high-energy short-pulse laser in the future when such systems become available at the required energy range and sufficient robustness.