

# Laser system design for table-top X-ray light source

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## Abstract

We present possible conceptual designs of a laser system for driving table-top free-electron lasers based on terahertz acceleration. After discussing the achievable performances of laser amplifiers with Yb:YAG at cryogenic and room temperature and Yb:YLF at cryogenic temperature, we present amplification modules with available results and concepts of amplifier chains based on these laser media. Their performances are discussed in light of the specifications for the tasks within the table-top light source. Technical and engineering challenges, such as cooling, control, synchronization and diagnostics, are outlined. These concepts for the laser layout feeding the accelerator are eventually derived and presented.

**Keywords:** concept; free-electron laser; lasers; optics

## 1. Introduction

Several laser facilities for strong-field physics experiments such as generation of attosecond pulses<sup>[1]</sup>, electron acceleration<sup>[2]</sup>, proton acceleration<sup>[3, 4]</sup> or X-ray generation<sup>[5]</sup>, have been or are currently being built around the world. These facilities contribute to numerous advances in science, including physics, chemistry, biology, medicine and material science. Their development constantly faces technological and engineering challenges to reach the desired peak power, pulse energy, average power and lifetime.

The ‘table-top’ free-electron laser (FEL) powered by terahertz (THz) radiation proposed in the project ANSIS (Frontiers in attosecond X-ray science: imaging and spectroscopy) in 2016<sup>[6]</sup> is part of the current intense research on alternative technologies to traditional, radio frequency (RF) based FELs<sup>[6–8]</sup>, which are very powerful but complex, large and expensive structures. These devices are thus few in number, resulting in very high demand and very limited access. The scientific community greatly benefits from alternative light sources with reduced size, cost and infrastructure needs. This demand has instigated extensive research efforts aiming

the realization of ‘table-top’ light sources<sup>[9–12]</sup>. Nonetheless, all the proposed solutions, either directly or indirectly, take advantage from the recent progress in high-energy optical lasers, which are complex facilities.

Building an X-ray light source or other types of light sources entirely based on optical lasers requires a system capable of producing a multitude of diverse laser beams with various characteristics like center wavelength, spectrum, pulse duration and energy to serve as both drivers and diagnostic tools. In particular, for the ANSIS project, ultra-short ultraviolet (UV) pulses are required for electron generation, multiple beams of high-energy picosecond pulses are required for single-cycle THz generation and high-energy nanosecond (ns) pulses, with tailorable, tunable spectral and temporal profiles, are required for multi-cycle THz generation. In addition, the facility should run at high repetition rates with femtosecond level synchronization and stabilization. Such a system is highly complex and requires a combination of different laser technologies, some of which must be developed or customized. The right choice of technologies is crucial to its successful implementation and operation.

In this paper, we will first present the ANSIS project and derive the requirements of the driving laser system. Second, the available laser technologies will be reviewed. The third

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