

# 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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## **Table of Contents Selected Papers On Laser System Design**

1. Understanding the eBook Selected Papers On Laser System Design
  - The Rise of Digital Reading Selected Papers On Laser System Design
  - Advantages of eBooks Over Traditional Books
2. Identifying Selected Papers On Laser System Design
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Selected Papers On Laser System Design
  - User-Friendly Interface
4. Exploring eBook Recommendations from Selected Papers On Laser System Design
  - Personalized Recommendations
  - Selected Papers On Laser System Design User Reviews and Ratings
  - Selected Papers On Laser System Design and Bestseller Lists
5. Accessing Selected Papers On Laser System Design Free and Paid eBooks
  - Selected Papers On Laser System Design Public Domain eBooks
  - Selected Papers On Laser System Design eBook Subscription Services
  - Selected Papers On Laser System Design Budget-Friendly Options

6. Navigating Selected Papers On Laser System Design eBook Formats
  - ePub, PDF, MOBI, and More
  - Selected Papers On Laser System Design Compatibility with Devices
  - Selected Papers On Laser System Design Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Selected Papers On Laser System Design
  - Highlighting and Note-Taking Selected Papers On Laser System Design
  - Interactive Elements Selected Papers On Laser System Design
8. Staying Engaged with Selected Papers On Laser System Design
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Selected Papers On Laser System Design
9. Balancing eBooks and Physical Books Selected Papers On Laser System Design
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Selected Papers On Laser System Design
10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
11. Cultivating a Reading Routine Selected Papers On Laser System Design
  - Setting Reading Goals Selected Papers On Laser System Design
  - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Selected Papers On Laser System Design
  - Fact-Checking eBook Content of Selected Papers On Laser System Design
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
  - Integration of Multimedia Elements

- Interactive and Gamified eBooks

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