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Short Communication

Solid-state Laser Weapon with Power up to 500 kW and its Growth Prospects

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Abstract

The rapid development of solid-state (S-S) laser weapon (LW) systems in the United States, particularly fiber and slab technologies, signals a transformative shift in modern military capabilities. Lockheed Martin's advancements in spectral beam stacking have enabled lightweight fiber-based laser systems exceeding 300 kW, while General Atomics and Boeing's work on distributed slab gain lasers addresses key thermal management challenges. This article analyzes these leading approaches, evaluates their scalability, and discusses the growing strategic significance of mono-module disk lasers, based on historical insights from foundational Soviet laser physics [1-3]. The potential for achieving megawatt-class compact and light systems remains a critical frontier in LW development.

Introduction

Significant breakthroughs in LW technology, especially in S-S systems, have accelerated the development of compact and efficient directed-energy weapons. Notably, the United States has been at the forefront, with institutions like Lockheed Martin, General Atomics (GA), and Boeing pioneering systems with favorable weight-to-power ratios. This paper reviews current technical achievements in fiber and slab laser systems and reflects on the broader implications of disk laser technologies inspired by the early work of Academician N.G. Basov [4]. In the case of the fiber-based LW, the breakthrough involves the development of spectral stacking technology for high-power/energy laser beams, using the company's highly sophisticated combined optical articulation architecture, based on Wavelength Division Multiplexing (WDM), which was used to increase the bandwidth of optical links. The concept was first published in 1970 by Delange and by 1980 WDM systems were being realized experimentally. The second refers to a pioneering approach to creating a high-power/energy distributed gain laser system - a novel system based on thin slabs with semiconductor pumping. Let's examine the state of the art in the problem of implementing LW complexes in each case separately.

Technical overview of fiber and slab LW technologies

To facilitate clarity for readers, the two dominant LW system architectures under discussion—fiber and slab—are outlined below.

Lockheed Martin's fiber laser systems

Lockheed Martin's technology centers on spectral beam stacking, where multiple fiber laser modules emit at slightly different wavelengths. These beams are then optically combined to produce a single, high-power laser beam with enhanced efficiency and compactness. This architecture supports power scaling while maintaining excellent beam quality, enabling field-deployable systems with weight parameters around 5 kg/kW, which is highly suitable for tactical applications.

"Lockheed Martin" has provided the Department of Defense (DOD) with the most powerful LW ever built [5] as part of the US military's overall transition to countering airborne threats such as drones, missiles, mines and rockets with directed energy weapons. In recent years, the US Navy and Air Force have already begun testing military-grade LW for such purposes. However, "Lockheed Martin's" new S-S LW system is by far the most powerful that has been developed to date. Modern warfare presents a number of new and emerging threats, many of which require an entirely new approach to defense. The proliferation of everything from off-the-shelf drones to advanced hypersonic missiles has made the skies especially deadly and has challenged militaries around the world to find new and innovative ways to counter these increasingly effective tactics. Hoping to complement its Iron Dome missile system, which protects Israel from aerial threats, the Middle Eastern country has begun testing and deploying a laser defense system against drones and missiles known as the Iron Beam. In the US, the Navy and Air Force have also begun testing laser systems to defend against drones and anti-missiles, although neither has set a timeline for actual deployment. Most of these systems range in power from a relatively reliable 60 kW that can shoot down drones all the way up to the third class (about 1.300 pounds or 0,589 kg), and the "Iron Beam" system boasts an even higher average power of 100 kW that can sweep enemy missiles and mines out of the sky. With this new system, "Lockheed Martin" has surpassed all existing performance, promising a new era in laser defense

The 300 kW average power is the largest for the S-S LW ever built

"Lockheed Martin's" new laser uses an approach similar to that of the "Death Star" from "Star Wars" to create a 300 kW super-powered beam of light. Specifically, the LW complex uses a series of small individual lasers broken down into their constituent wavelengths and then combines those individual beams into one powerful beam of light that strikes missiles. According to the company, this "spectral beam stacking technology with a combined high-power/energy laser architecture" underpins "Lockheed Martin's" ability to build such a powerful system. "Lockheed Martin" has increased the power and efficiency and reduced the weight and size of high-power/energy LW systems, which reduces the risk to future field testing of such high-power/energy LW systems. Advanced Product Solutions, as it is clear from a statement of the defense giant. The same statement mentions that the system is not only the most powerful "high-power/energy LW system the company has delivered to date, but it also notes that the contractor delivered ahead of schedule, first set by the US Defense Department when they were awarded the contract as recently as 2019. As for how the DOD plans to use its new LW, the "Lockheed Martin" release states that the 300 kW class LW is ready for integration with DOD demonstration efforts, including the US Army "Indirect Fires Protection Capability-High Energy Laser (IFPC-HEL)" demonstration LW system [5].

Still testing, but in actual combat, such a HEL will be available very soon

As in the case of previous LW systems, which are still being tested and evaluated by the US Department of Defense, no date for actual deployment in the Army field has yet been announced. Press reports say that the LW systems will first undergo an additional rigorous evaluation in the US Army and only then enter the field forces. Whether this is true is hard to say. The "HELSI" LW system will participate in field demonstration trials with the army's "IFPC-HEL" system. This is how the company explains the projected completion date of the tests, which were originally planned for the end of 2022. With so much power, "Lockheed Martin's"new 300kW system LW is probably powerful enough to defeat the most reliable missile systems and even hypersonic missiles. Given the continuous improvement of such ABM systems, it seems to the military that it is only a matter of a very short time before these formidable ABM systems with such a significant output power begin to appear on the battlefield.

General atomics and Boeing's slab-based system

In contrast to the fiber-based systems, General Atomics (GA) and Boeing are pursuing a high-power laser architecture based on slab geometry and distributed gain amplification. This approach prioritizes efficient heat dissipation and system scalability by using thin plates (slabs) arranged in a series, each contributing to overall beam amplification.

Late last year, "GA" and "Boeing" teamed up to create a scalable, high power/energy LW up to 300 kW [6], mostly on spec, to show the US DoD that the "GA" distributed gain laser design was a rational solution to cooling problems. Which usually impose severe limitations on high-power/energy LW and its output parameters.

According to "GA" experts, the distributed amplification system has previously been a Cinderella for the creators of high-power/energy lasers. S-S slab lasers, are prone to overheating and require heavy and cumbersome cooling systems. In contrast, "Lockheed Martin" fiber lasers, do not have much of a cooling problem because they distribute the pump radiation among multiple fibers that are spaced far enough apart to effectively dissipate heat. Ultimately, to get an effective laser source, these independent beams must be combined into one, and spectral beam stacking systems tend to be expensive, complicated, heavy, and cumbersome.

"GA" 's distributed amplification system is essentially a series of slabs connected in series, each small enough to avoid the development of amplified spontaneous emission (ASE) as well as to efficiently dissipate its own heat. The radiation from the master oscillator enters the first plate, which amplifies it and passes it on to the second plate, and so on, avoiding significant losses to ASE. There are no heating problems, no need for a complicated stacking system, and it allows them to be packaged, in any convenient sequence. Hence the company's willingness to build its original scalable prototype without having to enter into an additional military contract for the generated radiation stacking system to do so.

Now the US Army practically owns a high-power/ energy S-S laser, and "GA" and Boeing were contracted by the "RCCTO's" Rapid Capabilities and Critical Technologies Office to build a demonstration LW system based on "GA's" 300 kW laser system with a beam aiming and target holding system and Boeing's precision target acquisition, tracking software. The demonstration LW system is packed with a version of the 7th generation distributed amplification design already demonstrated earlier [6]. The LW system uses two 7th generation laser heads in a very compact and lightweight package to achieve beam quality comparable to fiber lasers. According to company reports, a very simple opto-mechanical linkage design will be used, without the need for a complex and highly unreliable spectral beam stacking system. There is still no word on whether this LW complex will be mounted on aircraft, Final testing of the compact and lightweight complex without the critical need for additional beam output power is still pending, but in the submissions the LW complex is definitely for mobile use only. While the "GA" describes the built prototype as having a gigantic power, greater than anything used in the Army to date, the enormous power of this continuous S-S LW complex pales in comparison to another laser system proposed by the company, an ultra-short pulsed laser, which will release up to 5 TW of light power in a pulsed-periodic (P-P) sequence with a duration of 30 fs and a frequency of 50 Hz.

Commentary on technology viability and disk lasers

- **Cooling efficiency:** Fiber lasers distribute pump heat among narrow cores, while slab systems demand bulky cooling units. Disk lasers, especially in mono-module format, provide superior cooling due to thin active elements with much broader surface.

- **Scalability:** Fiber-based systems are nearing the upper limit (~ 500 kW) due to spectral addition complexity. Slab systems face diminishing returns with added slabs due to alignment and ASE issues.

- **Disk laser potential:** As described in the attached article Mono-модule disk laser—No Alternatives, disk lasers could support strategic-level power outputs (>1 MW) with lower weight parameters (< 2 kg/kW). The work by N.G. Basov remains foundational, especially for megawatt-class mono-module lasers capable of supporting space and atmospheric applications [3].

My comments on the proposed technologies for creating LW

The distributed amplification system is a series of "slabs" (thin plates) that mimic the same distributed amplification system of a fiber laser. The purpose of this enhancement is:

a) To reduce the number of beams at the output, which then have to be stacked into one. Two beams configuration of the two modules described in the distributed gain complex stack much more easily;

b) In preserving the convenience of cooling these radiation-amplifying elements of the system. In a fiber laser, this problem is solved much easier, because the fibers are hundreds of microns thick and the heat is dumped much more easily;

The cited articles confirm our experience of significant difficulties in the spectral addition of many beams of fiber lasers, as well as the cumbersomeness and low reliability of this optical system as a whole. This is particularly important to realize in the case of this technology for mobile complexes.

Our estimates (published in the Military Industrial Courier [2] about the large size of the laser system on "slabs" in comparison with the fiber laser system and its significantly higher weight due to the design features of such laser systems are also confirmed;

It has been argued that the beam quality of the slab-based LW system is comparable to that of the fiber-based system. There are legitimate questions here, to beam quality, which the article does not address or does so deliberately;

The quoted articles clearly refer to the wheeled version of the LW complex being developed by "GA" and "Boeing"[6]. The airborne version requires additional effort. For example, with a total size of 250 inches (635cm) for the reinforcing part of the complex, the "Boeing's" VIP requires that 18 inches (45.7cm) of the complex length be removed. There is no mention of the total weight of the final product in the sources discussed, but the wheeled version is unquestionable. And that means that the "Laser Monster" in this case is obvious;

The 300 kW LW complexes are compared with the femtosecond P-P complex of huge power being developed in the US, which generates 5 terawatt pulse series ("tsugs"), but at much lower total system energy. This suggests a lack of understanding of the true purpose of the complexes discussed and does not look quite professional. But, at the same time, it does inform a curious reader about the capabilities of the US laser specialists to use a terawatt "tsug" laser and its significant capability to functionally ("smart") engage a target;

Discussion

While fiber and slab laser technologies represent robust solutions for near-term deployment, both face significant challenges on a strategic scale. The complexity of beam combining in fiber lasers and the mass and size issues of slab systems may preclude their application in megawatt-class space or mobile systems.

Limitations of the current study

- Lack of peer-reviewed experimental validation of claimed performance (data are mostly derived from public statements and defense contractor releases).- There is no published quantitative modeling or simulation of cooling, pumping and ASE supression in the mono-module disk systems included in this study.

Future research directions

- Investigation of disk lasers, a concept first proposed by Russian physicist N.G. Basov [4], with large diameter (up to 60 cm) active elements incorporating advanced ASE suppression.

- Exploring the use of regenerative amplification in high-frequency P-P systems for functional / force mode of interactions and set of exciting civil applications [7-10].

Materials science innovations in highly reflective, thermally stable mirror coatings to support multi-megawatt optical loads.

In the US, parallel work is underway to test prototype S-S laser systems on fiber (<5 kg/kW) and "slab" (>50 kg/kW) bases with appropriate weights and dimensions to enable efficient land, sea, and airborne applications. The next stage of development is preparing these technologies for space applications;

It also seems obvious that the process of power scaling of complexes is close to saturation and creation on these physical-technical and technological bases of complexes of megawatt class with acceptable mass-size characteristics is practically impossible;

The disk geometry of the working body of the N.G. Basov LW complex in combination with the solutions we have found to suppress the development of ASE at a large disk diameter remains the only candidate capable of advancing tactical laser systems in strategic;

The new geometry of the mono-modular disk laser requires the development of a new element base, which allows to further reduce the weight parameter to values less than 2 kg/kW.

Conclusion

The rapid progress of S-S LW technologies - especially fiber and slab architectures - marks a turning point in directed energy systems. However, as both approaches face physical and scale limitations, mono-modular disk laser architectures are emerging as a promising alternative for the next generation of LW complexes. Recently, a 500 kW fiber laser based on the same technology - spectral beam stacking - has been reported in the USA, which is close to the limit of further scaling. It follows that for solving the problems of "D. Trump's Golden Dome program" the obtained results seems to be insufficient. The search for a solution to the problem of strategic LW remains relevant.

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