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لیزر دیسک نازک Q-Switch پرتوان

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چکیده- در این مقاله طراحی و ساخت یک لیزر دیسک نازک Yb:YAG پالسی با توان متوسط حدود ۳۰۰ وات ارائه شده است. مدولاسیون اتلاف تشدیدگر، با استفاده از سلول آکوستو-اپتیک انجام شده است. وابستگی انرژی پالس‌ها و توان متوسط خروجی به توان دمش و همچنین نرخ تکرار بررسی شده است. مقدار توان دمش و همچنین نرخ تکرار در محدوده‌ای انتخاب شدند که منجر به پالسهای لیزری پایداری شوند. نشان داده شد که در نرخ تکرارها و توانهای دمش بالا انرژی پالس‌های خروجی وابستگی کمتری به پارامترهای مذکور دارند. لیزر ساخته شده در گستره نرخ تکرار ۰.۵ تا ۱۰ کیلوهرتز، با پهنای زمانی پالس حدود ۱ میکروثانیه، به صورت پایدار کار می‌کند. بیشینه انرژی پالس خروجی ۵۷ میلی‌ژول بود که در نرخ تکرار ۱ کیلوهرتز به دست آمد. مطابق بررسی‌های ما مقدار توان متوسط گزارش شده در این مقاله، بیشترین توان بدست آمده برای لیزرهای دیسک نازک به روش Q-switch می‌باشد.

کلید واژه- سویچ **Q**، لیزرهای پرتوان، لیزر دیسک نازک.

High Average Power Q-Switched Thin-Disk Laser

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Abstract- Design and fabrication of a high-average power Q-switched Yb:YAG thin-disk laser with average power of about ۳۰۰W is presented. Modulation of the resonator loss is done using an acousto-optic cell. The dependency of the output pulse energy and average power on the pump power as well as the repetition rate was investigated. The values of these parameters are chosen in a range that the laser produces stable pulses. It was shown that the energy of the output pulses at enough high repetition rate and high pump power is less dependent on these parameters. The laser is stably operated in the repetition rate range of ۰,۵ to ۱۰ kHz, with pulse width of about ۱ microsecond. The maximum output pulse energy was ۵۷ mJ which measured at the repetition rate of ۱ kHz. To the best of our knowledge, it is the highest average power that has been reported in Q-switched thin-disk lasers.

Keywords: High average power, Q-Switching, Thin disk laser.

١. Introduction

Thin-Disk Lasers (TDLs) are based on a thin gain medium with large diameter. Because of the large ratio between the diameter and the thickness of the disk, the heat flow along the beam axis is nearly one-dimensional, which leads to small thermal distortions. Excellent heat removal capabilities provides good beam quality even in high average powers, enabling them to be widely used in science and industry [١, ٢]. High average power lasers with many hundred nanosecond and microsecond laser pulses are very important in industrial applications. Q-switching is the simplest and common technique to produce laser pulses in nanosecond and microsecond ranges. This method is based on switching the laser cavity loss by a controllable element inside the laser resonator. Although Q-switching is relatively popular method for laser pulse generation in solid-state lasers, most of the reports in thin disk lasers are based on cavity-dumping, and Q-switching have not been well studied in TDLs [٣, ٤].

In this paper the characteristics of an acousto-optically Q-switched Yb:YAG thin-disk laser, with high average power are presented. The dependence of the average power and the pulses energy on the Q-switching repetition frequency and pump power is investigated.

٢. Design

To extract high average power pulses, a thin-disk laser module designed and constructed in Iranian National Center for Laser Science and Technology (INLC). Schematic of the performed laser set-up is shown in Fig. ١. Because a specific pumping diameter (~٥,٥ mm) is needed on the disk surface for high power pulse generation, all parts of the laser separately designed specifically for this project. As shown in Fig. ١, the designed laser set-up consists Yb:YAG as active medium of the laser, a V-shaped resonator, pumping system and a jet-impingement cooling structure.

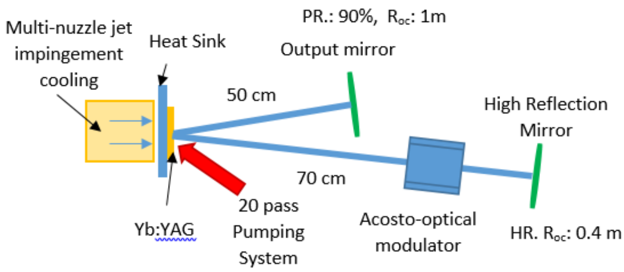

Fig.١: Schematic of laser set up.

The Yb:YAG crystal is soldered on a Cu-W heat sink, which made a uniform temperature profile on the disk surface under the pumping power.

The pumping utilizes by a stack diode bar with central wavelength in ٩٤٠ nm. The pumping light is homogenised by a light-pipe and imaged on the disk surface by an optical set-up consisting cylindrical and spherical lenses and a parabolic mirror. The un-absorbed pumping light re-imaged on the disk by a multi-pass (٢٠ passes) optical set-up. This laser is designed to produces maximum ٦٠٠W output power in CW operation. The gain module elements are designed specifically for this laser, but fundamentally discussed with more details in our previous reports[٥, ٦].

The resonator of the laser is designed by laser cavity analysis and design (LASCAD) software, considering clear aperture of the modulator crystal. ~~maximum overlap of the pumping diameter and the resonator transverse mode and~~ The resonator was designed so that works dynamically stable in the pumping power range [٧]. The beam quality factor ($M^٢$) of the output beam was predicted to be less than ٢٤ in the pumping power range.

Q-Switching is performed by an acosto-optical cell, driven by a radio frequency (RF) generator. The RF signal frequency and duration is controlled by an external transistor-transistor logic (TTL) signal.

۳. Results and discussion

For safety of the disk and other optical elements of the laser, the pulse shape and energy were monitored during the experiments. All measurements were conducted within the stability region of the laser, ~~pulses~~ considering laser induced damage threshold (LIDT) of the optical elements, especially the disk. The repetition rate and the pump power density determine the borders of this region. Outside this region, there is the possibility to generation of high energy pulses which can damage optical elements [۸].

Figure ۲ shows the pulse energy as a function of repetition rate for different values of incident pump power. The maximum measured pulse energy was $57\,mj$ that obtained at repetition rate of $1\,kHz$ and pump power of $525\,W$.

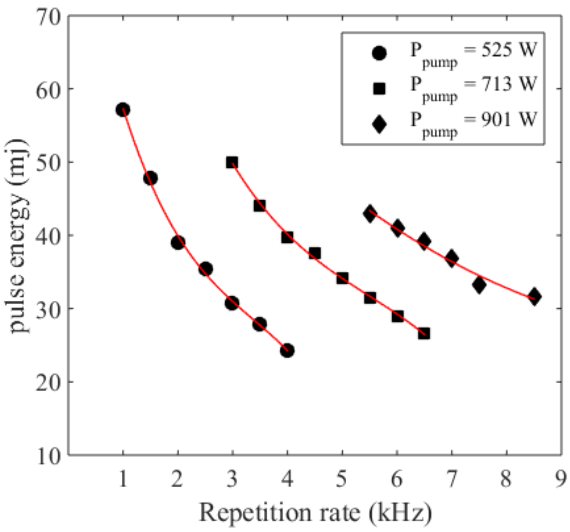

Fig. ۲: The variation of pulse energy versus repetition rate for three different pump powers.

Increasing the repetition rate, in a constant pump power, leads to decreasing the pulse energy, as expected. This trend is observed for all pump powers, but slower variation of pulse energy versus the repetition rate at higher pump powers is noticeable.

Figure ۳, shows the variation of the pulse energy as a function of incident pump power for different repetition rates. It is clear that the pulse energy shows softer dependency on the pump power at higher repetition rates. Indeed, in this condition the population inversion oscillates around near its maximum value and further increase of the pump power leads to appearing the saturation effect, as shown in curve $9.5\,kHz$ of Fig.۳. It is noticeable that at each repetition rate, the upper limit of the pump power restricted by LIDT.

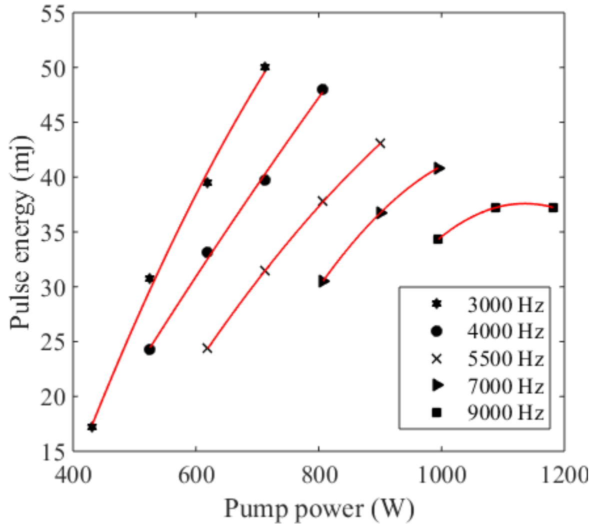

Fig. ۳: The pulse energy as function of pump power for different repetition rate.

The average pump power of the laser for some different repetition rates is shown in Fig. ٤. Even though the pulse energy decreases at higher frequencies but the more energy could extracted from the active medium.

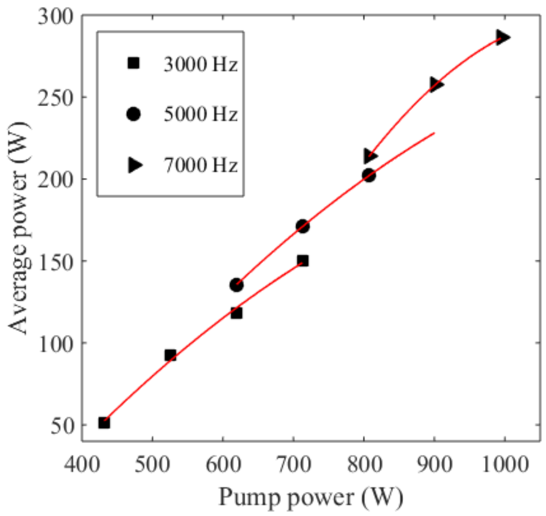

Fig. ٤: The output average power versus pump power for three different repetition rates.

In Fig. ٥ the time profile of output pulses at repetition rate of $3kHz$ and under pump power of $620\ W$, which was recorded with a fast photodiode, are shown. As cab be seen, the pulse width is around $1\mu s$.

Noteworthy, we measured the pulse width of the output pulses for all laser operational conditions. Generally, it was found that the time duration of pulses increases with frequency and the rate of variation depends on the pump power density on the disk surface. The faster rate was observed at lower pump powers. However, these variations are limited within a small rang.

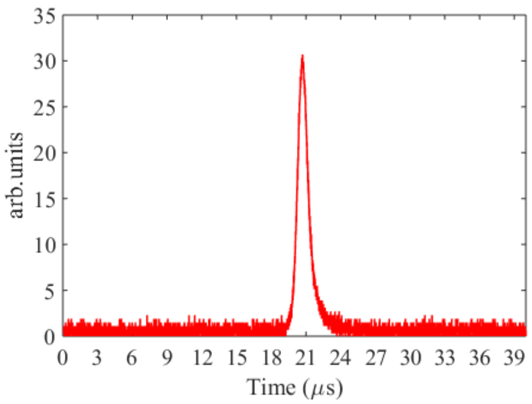

Fig. ٥: The time profile of output pulse at repetition rate of $3kHz$ and pump power of $620\ W$.

۴. Conclusions

In summary, a high average power, acousto-optically Q-switched Yb:YAG thin disk laser was designed and constructed. The characteristics of laser output were measured under various pump power and repetition rates. The maximum single pulse energy of ٥٧ mj was measured at repetition rate of $1kHz$ and pump power of $525\ W$. The average output power near ٣٠٠ W was recorded at $7\ kHz$ and $525\ W$ repetition rate pump power, respectively. The time duration of output pulses was around $1\mu s$.

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با عرض سلام و احترام

نویسندگان مقاله از داور محترم به جهت فرصتی که جهت بازبینی دقیق مقاله و ارائه پیشنهادات سازنده اختصاص داده اند نهایت تشکر و امتنان را دارند. متن مقاله بر اساس نکته نظرات ۱، ۲، ۴، ۵، ۶، ۷، ۱۰و ۱۱ طبق نظر داور محترم اصلاح شد. در مورد سایر نکته نظرات در ادامه توضیحات مبسوط داده شده است.
نویسندگان مقاله از سوالات و کامنت‌های بیشتر استقبال می‌کنند.

کامنت های ۳ و ۱۲) اندازه‌گیری کیفیت و پروفایل باریکه:

۱- اندازه‌گیری پروفایل و کیفیت باریکه: نویسندگان مقاله از اهمیت کیفیت باریکه در لیزرهای توان بالا برای کاربردهای صنعتی آگاه هستند، از این رو در طراحی اولیه رزوناتور V-شکل با استفاده از نرم‌افزار LASCAD هدف گذاری ما کیفیت باریکه زیر ۲۴ بود. یعنی حتی با تغییر شعاع انحنای دیسک با بالا رفتن دما در توان‌های دمش بالا کیفیت باریکه زیر ۲۴ می‌ماند. با این حال تمرکز ما در این مرحله از تحقیق تولید پالس‌های میکروثانیه با توان میانگین بالا از دیسک بود. به همین علت، در این مرحله کیفیت باریکه اندازه‌گیری نشده است.

کامنت ۸) منحنی تغییرات دیوپتر دیسک:

۲- تغیرات شعاع انحنای دیسک بر حسب توان دمش را با استفاده از تاباندن یک جبهه موج تخت به دیسک و اندازه گیری جبهه موج بازتاب شده با استفاده از سنسور شاک-هارتمن اندازه گیری می‌شود. با این کار شعاع انحنای دیسک را در هر توان دمشی خواهیم داشت. برای دیسک مورد استفاده ما محدوده تغییرات شعاع انحنای دیسک از ۴,۷ متر در دمش صفر تا حدود ۷ متر در حداکثر توان دمش بود. با این حال از گزارش این اندازه‌گیری‌ها با توجه به هدف مقاله صرفاً به طراحی تشدیدگر بسنده شده است. قابل ذکر اینکه قبل از راه‌اندازی لیزر چندین تست مختلف در شرایط کاری متمایز روی لیزر و دیسک انجام می‌شود. برای مثال منحنی تغییرات توزیع عرضی دمای دیسک در توان دمش‌های مختلف و سایر تست‌های سنجش کیفیت لایه های مختلف دیسک. همانطور که اشاره کردیم در مقالات این تست‌ها توضیح داده نمی‌شود.

کامنت ۹) رسم منحنی یکی از پارامترهای دینامیکی لیزر یا رزوناتور بر حسب توان دمش:

با توجه به اینکه توان متوسط و انرژی پالس ها بر حسب توان دمش در مقاله ارائه شده است، ما متوجه منظور داور محترم از این کامنت نشدیم.

با تشکر فراوان