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Investigations of single frequency generation in passively Q-switched Nd:YAG laser end pumped by 10 W fiber coupled diode bar

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Passively Q-switched Nd:YAG laser with output averaged power of about 1 W and pulse power of about 1 kW has been demonstrated. LiF crystal with $[F_2^-]$ colour centers was applied as a passive Q-switch and 10 W fiber coupled diode bar used as a pump source. Investigations of pulse duration, repetition rate, energy and power were performed. Single frequency spectrum was evidenced by means of Fabry–Perot interferometer.

1. Introduction

High peak power, high repetition rate light sources are required in numerous applications, such as range finding, optical scanners, coherent pumping, *etc.* Pulsed laser diodes [1]–[3], as well as Q-switched diode pumped solid state lasers (DPSSL's) [4]–[15] c an satisfy such requirements. The disadvantages of pulsed laser diodes, namely, multimode output, poor beam quality, relatively low pulse power limited to 100–200 W, are compensated by low-cost, low size and long lifetime.

High repetition rate Q-switching of DPSSL is usually accomplished with an acoustooptic [5], electrooptic [6]–[9], passive modulator [10]–[15], although mechanical shutter [4] or gain switching may be applied with success. In some applications, single frequency, smooth pulses, with pulse powers above 10 kW, are required, which can be realized in some types of Q-switched DPSSL's. In the case of electrooptic Q-switching it is possible to obtain smooth pulses evidencing single frequency generation by applying prelasing technique [8], [9], although there are problems with high repetition rate Pockels cell drivers required for this purpose. In the case of passive Q-switching single axial mode generation occurs as a rule because of relatively long pulse build-up time. Moreover, passive Q-switching, offers other advantages, such as low cost, no high-voltage or RF drivers required, *etc.*

The aim of this paper is to practically verify generation of single frequency, high repetition smooth pulses in Nd:YAG laser passively Q-switched by means of LiF crystal with $[F_2^-]$ colour centers (LiF$[F_2^-]$).

2. Investigations of temporal and energetic parameters of the laser

Investigations of passively Q-switched generation were carried out in the set up shown in Fig. 1. In the first part of experiments we measured parameters of the laser working in free-running mode. As an active medium Nd:YAG crystal 1% at. doped with diameter of 4 mm and length of 10 mm was used. As a pump source cw fiber coupled diode bar SDL3450-P5 emitting 12 W of cw pump power was applied. The

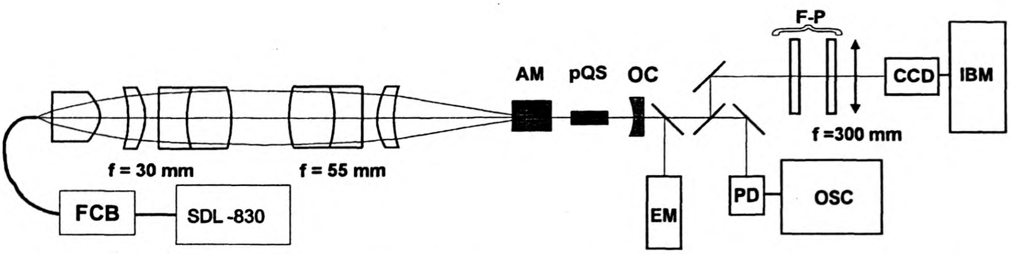

Fig. 1. Scheme of experimental set up SDL-830 – laser diode driver, FCB – fiber coupled diode bar, AM – active medium Nd:YAG crystal, pQS – LiF:[F_2^-] crystal with initial transmission 65%, OC – output coupler with 10% transmission and 200 mm radius of curvature, EM – energy meter, PD – photodetector, F–P – Fabry–Perot interferometer with basis of 10 mm, CCD – CCD camera, IBM – PC computer 486, OSC – digital or analog oscilloscope

beam shaping optics formed a caustics with 1 mm diameter and Rayleigh range of about 3 mm inside the rod. We obtained 53% slope efficiency with 4.5 W output power of multimode generation in 30 mm short flat – flat cavity with 5% output coupler. For Q-switching experiments the cavity was elongated to 110 mm and output coupler with 10% transmission and 200 mm radius of curvature was applied. LiF:[F_2^-] crystal with initial transmission of 65% was used as a passive Q-switch. For higher level of pump power we observed the heating of both crystals. Thus, we carried out all experiments in a quasi-cw regime with a duty factor of 50% and pump duration of 2 ms. Results of output power measurements for free-running and Q-switched case are presented in Fig. 2. A very high slope efficiency (about 59%) was achieved in free-running mode, whereas in a Q-switched case it decreased to 14%.

According to theoretical predictions, pulse energy, pulse power and repetition rate linearly increased with pump power (Figs. 3, 4). As a rule the smooth pulses with duration (25–40 ns) decreasing with pumped power were observed (Fig. 5).

3. Investigations of Fabry–Perot spectrum of generation

To investigate single frequency generation Fabry–Perot interferometer with basis of 10 mm was applied. Spectrum was registered by means of a CCD camera placed in the back focal plane of lens with 300 mm focal length (see Fig. 1).

In the case of free-running mode the axial and transversal multimode genera-

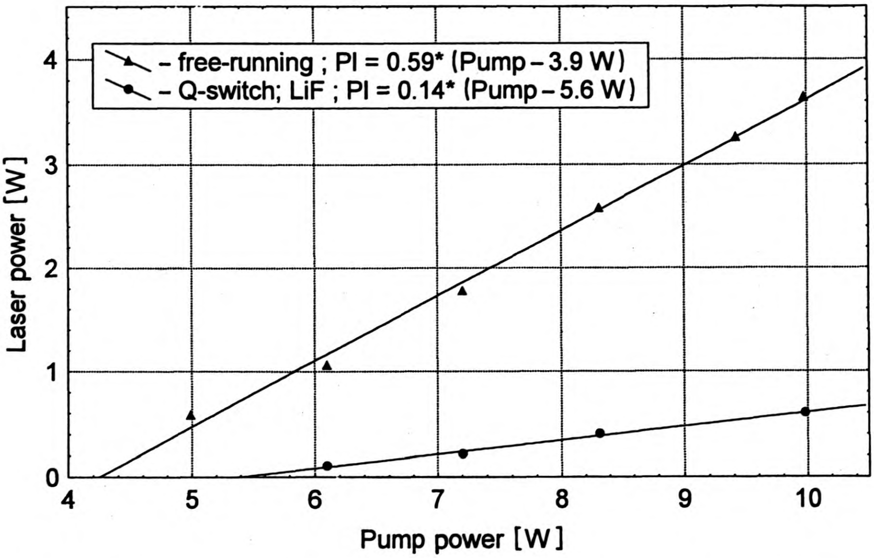

Fig. 2. Output power versus pump power for free-running and Q-switched generation

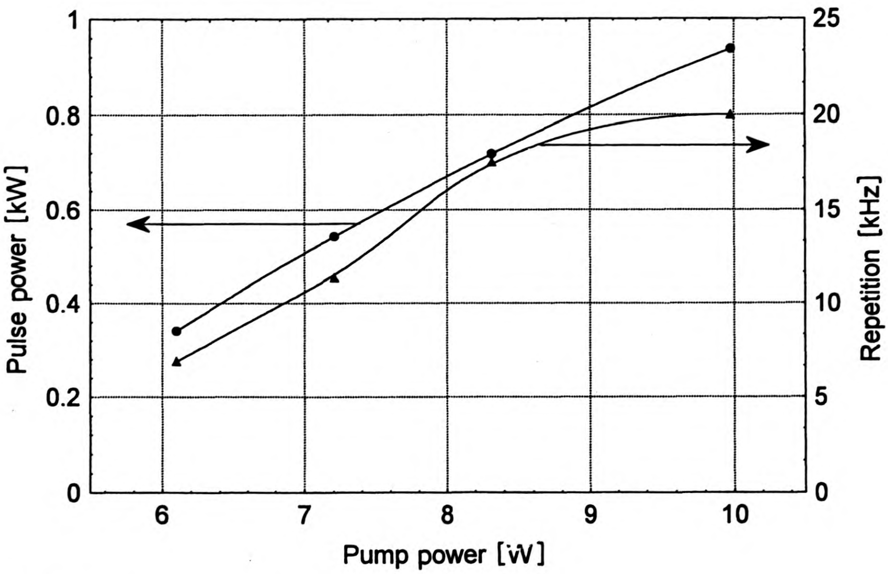

Fig. 3. Pulse power and repetition versus pump power

tion was evidenced (Fig. 6). In the case of Q-switched generation, one-, two- or three-axial modes were observed (Fig. 7**a**,**b**). Because of limited exposure time of the camera (typically, 10–30 ms) a spectrum of several pulses was registered simultaneously. As we pointed out in [9], [15], such effect of "quasi-multimode spectrum" can be caused rather by the method of measurement than the real features

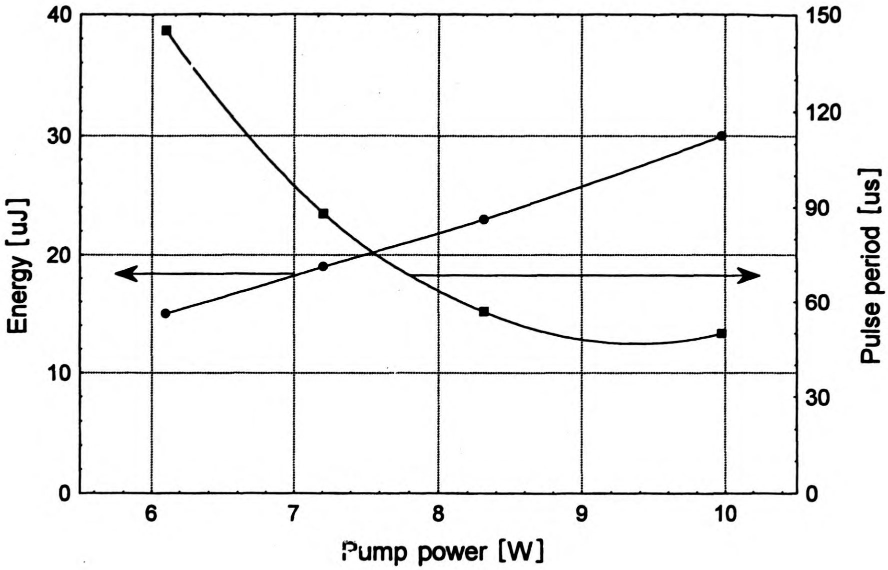

Fig. 4. Pulse energy and pulse period versus pump power

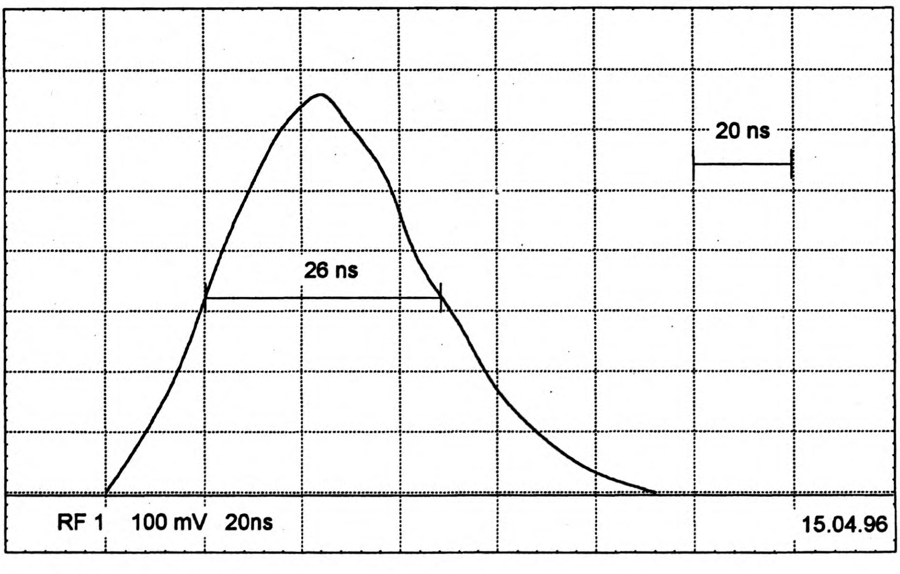

Fig. 5. Pulse profile for pump current 25 A

of generation. Using analog oscilloscope, we observed pulse profiles to be very stable in magnitude, but unstable in time domain. The jitter of pulse period can be estimated at about 5–10%. Each pulse starts at different point on gain bandwidth because of spatial hole burning effect and thermal instabilities of cavity, resulting in averaged multimode Fabry–Perot spectra observed by means of the CCD camera.

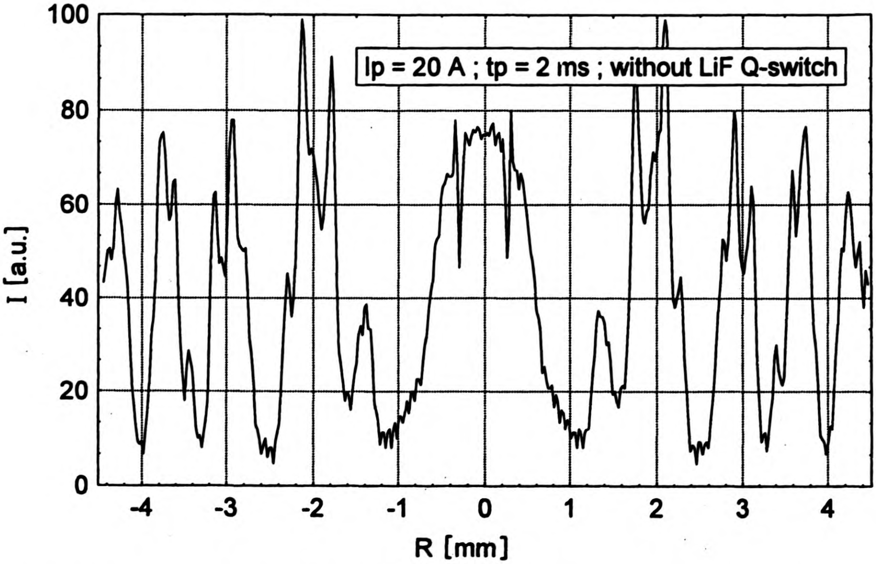

Fig. 6. Fabry—Perot interferogram of multimode spectrum of free-running mode

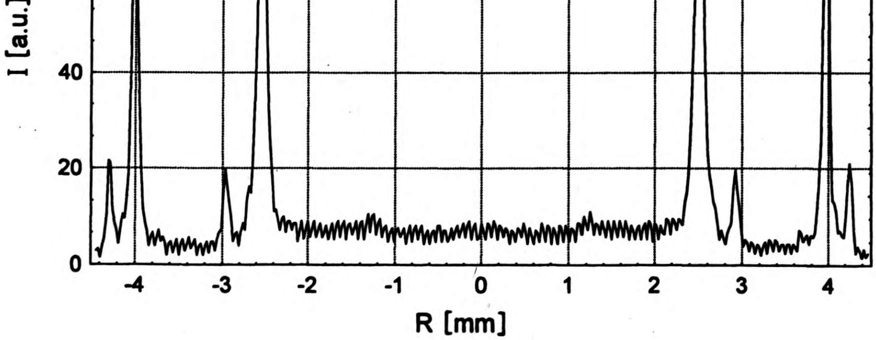

Fig. 7a

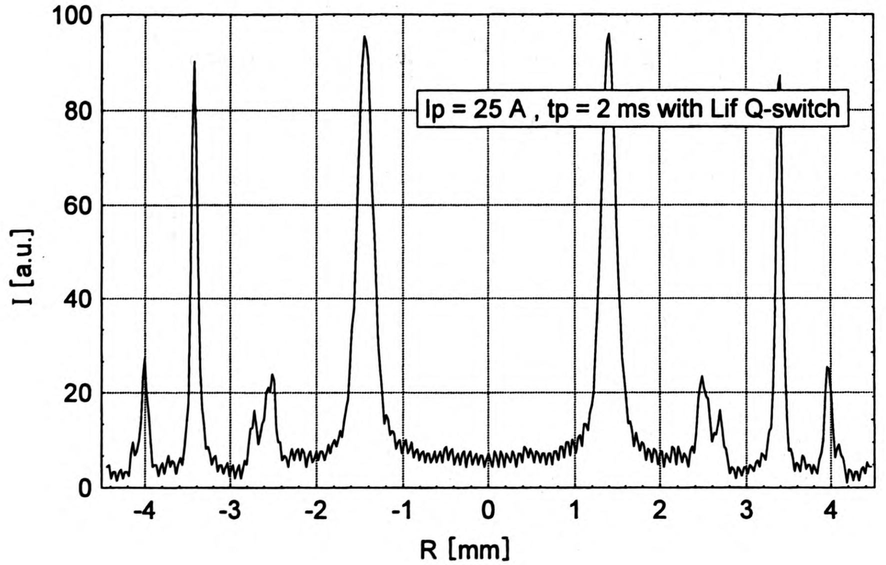

Fig. 7b

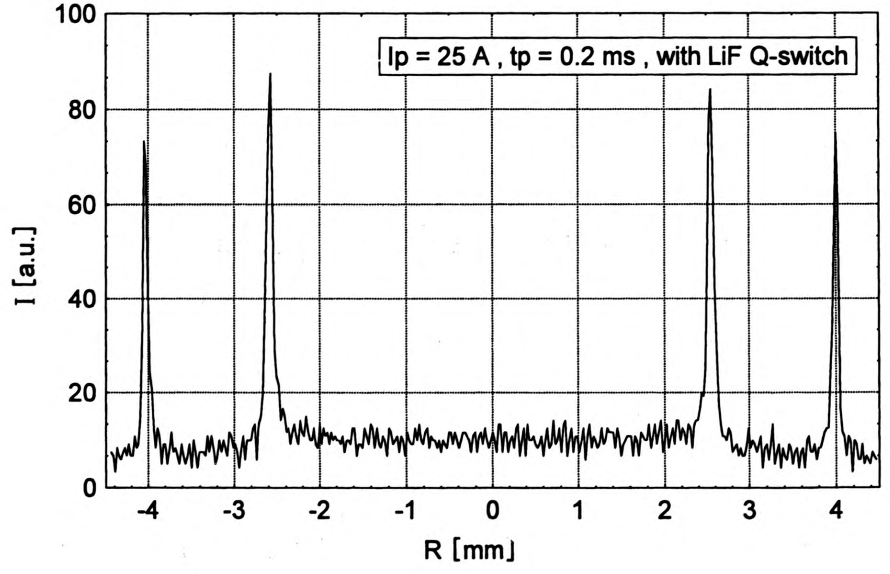

Fig. 7c

Fig. 7. Fabry–Perot interferograms of Q-switched generation. **a** — for pump current 20 A and pump duration 2 ms, **b** — for pump current 25 A and pump duration 2 ms, **c** — for pump current 25 A and pump duration 0.2 ms

To verify this phenomenon we registered Fabry–Perot spectrum for pump duration of 0.2 ms, for which only one Q-switched pulse can be generated. As was shown in Fig. 7c, a single frequency generation was observed in this case.

5. Conclusions

We demonstrated single frequency, slightly unstable generation in a passively Q-switched Nd:YAG laser. The output averaged power of about 1 W was achieved with pulse power at 1 kW level. The instabilities of pulses in time domain were caused by thermal instabilities of LiF:[F_2^-] crystal and thermally induced aberrations of active medium. We used here LiF:[F_2^-] crystal without antireflection coatings, though cavity losses were high. Pulse duration at level 20–30 ns can be significantly shortened by enhancement of laser elements and shortening of cavity. The energetic results presented in this paper should be considered as preliminary ones and we expect significant progress in next experiments. Nevertheless, such high repetition, high pulse power laser source can find wide applications, *e.g.*, in coherent pumping, laser spectroscopy, optical scanners, *etc.*

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References

[1] Akkapeddi P., Macomber S. H., Proc. SPIE **1416** (1991), 44.
[2] Doyle McClure J. Proc. SPIE **1219** (1990), 446.
[3] Gorfinkel V. B., Kompa G., Sola J., Volge F. P., Digest of *Conference on Lasers and Electro-Optics Europe'94*, 1994, paper CMD2.
[4] Scheps R., Myers J. F., Appl. Opt. **33** (1994), 969.
[5] Grossman W M., Gifford M., Wallace R. W., Opt. Lett. **15** (1990), 622.
[6] Afzal R. S., Selker M. D., Opt. Soc. Am. Proc. *Advanced Solid State Lasers* **24** (1995), 402.
[7] Godfried H. P., Offerhaus H. L., Opt. Soc. Am. Proc. *Advanced Solid State Lasers* **24** (1995), 420.
[8] Rae C. F., Terry J. A. C., Sinclair B. D., Dunn M. H., Sibbett W., Opt. Lett. **17** (1992), 1673.
[9] Jabczyński J. K., Żendzian W., Opt. Appl. **26** (1996), 35.
[10] Morris J. A., Pollock C. R., Opt. Lett. **15** (1990), 440.
[11] Chen Y. C., Shiqun Li, Lee K. K., Zhou S., Opt. Lett. **18** (1994), 1418.
[12] Braun B., Kartner F. X., Keller U., Meyn J. P., Huber G., Chiu T. H., Opt. Soc. Am. Proc. *Advanced Solid State Lasers* **24** (1995), 434.
[13] Isyanova Y., Welford D., Opt. Soc. Am. Proc. *Advanced Solid State Lasers* **15** (1994), 20.
[14] Pfeiffer A., Heinemann S., Mehnert A., Schmitt N. P., Peuser P., *Proc. Int. Congress Laser'93: Laser in Engineering*, 1994, 94.
[15] Zayhowski J. J., Opt. Lett. **20** (1994), 1427.

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