Application Notes

Boosting of SLD Power. Feedback-Insensitive, Ultra-High-Power MOPA SLD Sources.

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Performance of ultra-high-power SLDs

MOPA system, experimental results

Advantages of MOPA configuration

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Performance of ultra-high-power SLDs

Research, development and manufacturing of the state-of-the-art, broad-spectrum, powerful light sources basing on superluminescent diodes (SLDs) is the Superlum's core business since 1992. On a way of developing of such SLDs a lot of challenging tasks had been successfully solved, including optimization of an SLD structure and coating procedures, a highly-efficient reflection-free coupling to SM fiber by angle-polished cylindrical microlens on the end of fiber [1], and others. These technologies are widely used in our HP-series SLD modules and traveling wave amplifiers with fiber-to-fiber gain exceeding 30 dB.

However, powerful SLDs have one significant drawback, namely, a strong sensitivity to optical feedback due to a very high optical gain in active region [2]. Such SLDs should be used with optical isolators if a feedback from an optical system may exceed 0.1%. Weak feedback of 1% may significantly decrease SLD output power and change its spectrum. In certain cases, it may result in a catastrophic ("fatal") SLD failure.

SLD protection from optical feedback is easy at telecom wavelength windows where isolators are low-loss, very compact and inexpensive. But it turns to a serious problem at shorter wavelengths, especially below 1000 nm, where isolators are bulky, lossy and expensive.

Particularly, our today's products at 800 - 1000 nm band are limited by 30 mW SM-fiber power (50 mW free space). Such SLDs require -30 dB isolation and any minor feedback may result in their latent or fatal damage. Due to this we recommend to use such SLDs with isolators independently on estimation of possible optical feedback in the system. In fact, optical feedback of 0.01% already affects power of such SLDs [2].

On the other hand, we can make single mode SLD emitters capable to deliver 200 mW of a free space power without COD. Light-current characteristic and spectrum of such an SLD at 840 nm is shown on the Fig. 1. Commercial SLD modules with output power exceeding 50 mW in SM fiber and 100 mW in a free space are possible basing on such emitters. But applications for such devices may be very limited due to the feedback issue.

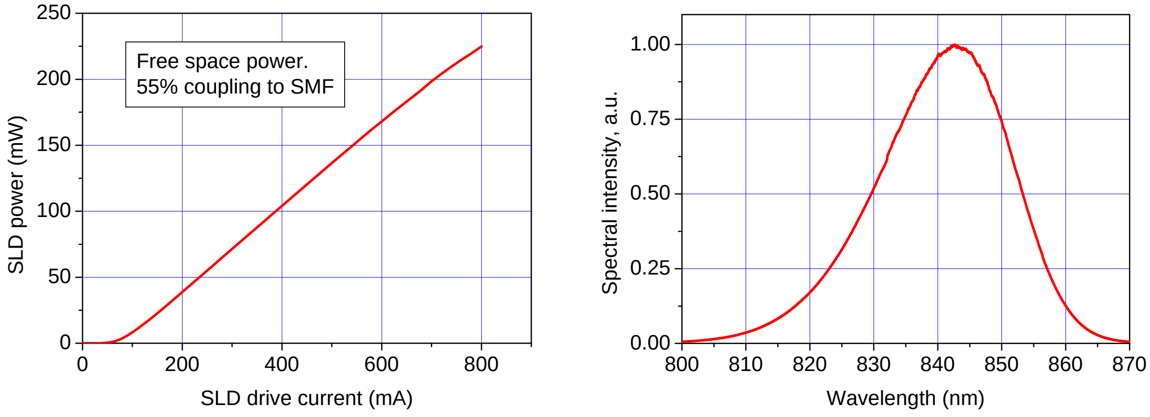

Fig. 1. Light-current characteristics of high-power SLD at 840 nm and its spectrum at 150 mW free space power. Coupling efficiency to SMF: 55% by polished cylindrical microlens on the fiber end. COD (catastrophic optical damage of output facet): 250 mW.

For example, 50 mW SMF (100 mW free space) SLD requires optical isolation better than -40 dB for its stable and safe operation. Single-stage broadband isolators at 800 - 900 nm wavelength have typically -20…-25 dB isolation and 1.5 – 2 dB insertion losses. When such isolator is used with today's 30 mW SM fiber SLD, output power becomes 20 mW after isolator. Two isolators will be required to isolate 50 mW ex fiber SLD and total losses of 3–4 dB are expected. So "useful" output power of a "feedback-independent" light source based on a 50 mW ex-fiber SLD will be only 25 mW, just 5 mW more with respect to a "single-isolator" light source based on a commercially available 30 mW 840 nm SLD. In fact, sensitivity to optical feedback becomes a serious limit for practical applications of ultra-high-power SLD light sources.

MOPA system, experimental results.

Therefore, an alternative approaches for an effective increasing of power of SLD-based light sources should be considered if an "ultra-high" power is required by a particular application. One of such approaches may be so-called "MOPA" (Master-Oscillator-Power-Amplifier) configuration in which the light from a medium power "master" SLD is amplified by an appropriate SOA of the same wavelength.

The main advantage of such a configuration is its small sensitivity to optical feedback if the "master" SLD saturates SOA. Let us assume power of the master (SM fiber coupled) SLD is 4 – 5 mW. Unsaturated (small-signal) fiber-to-fiber gain of our SOAs is around 30 dB. Master power of 5 mW will immediately saturate gain; however, estimations show that optical gain up to 10 dB will be still within reach. Therefore, output power of 50 mW may be expected, with an "acceptable" sensitivity to optical feedback. For example, 4% feedback to SOA module (which corresponds to normal cleave of SOA output fiber), should affect output power by around 10% only. And it should not affect output spectrum of MOPA source because SOA is strongly saturated. Optical feedback of 10% may decrease output power by two times (to about 25 mW) although it unlikely changes optical spectrum of MOPA, too. It is not the less important (probably, even more important) that neither case should result in any fatal or latent damage of a SOA crystal.

Fig. 2 below shows details of MOPA system. Master SLD with a relatively broad spectrum centered around 840 nm was followed by an appropriate optical isolator and polarization controller. SLD with output power up to 6 mW was used in this experiment.

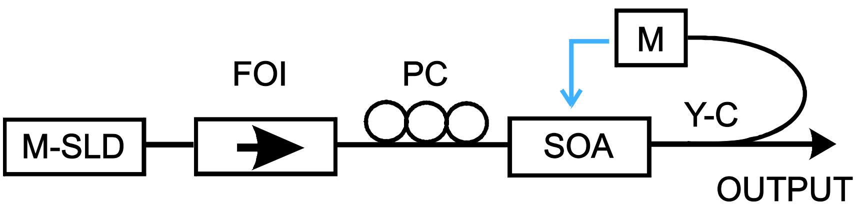

Fig. 2. Schematic sketch of MOPA source.
M-SLD – master SLD;
FOI – fiber optic isolator;
PC – polarization controller;
SOA – amplifier;
Y- C – 5% / 95% (used in case of constant power operation mode);
M – power monitor.

A new prototype, SOA-382-HP amplifier module which is similar to standard SOA-382 (http://www.superlumdiodes.com/pdf/soa382.pdf) but allows higher operation power was used to boost SLD power. (SOA-382 amplifiers are based on extremely-high-power SLDs described above). Fig. 3 shows light-current characteristics of the "MOPA" light source in case of no optical feedback, and 4% feedback.

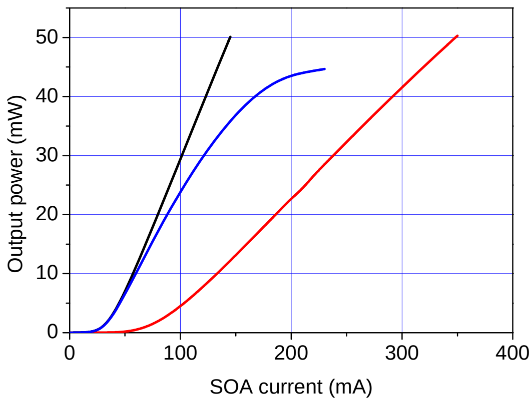

Fig. 3. Light-current characteristics of MOPA.
Red: free-running SOA-382 (angle cleaved output fiber)
Black: 5 mW master SLD power (angle cleaved output fiber)
Blue: 5 mW master and 4% feedback to SOA
(normal cleaved output fiber)

Fig. 4 presents spectrum at the MOPA output. 3-dB spectrum width is 12 nm; residual spectral modulation is well below 1%.

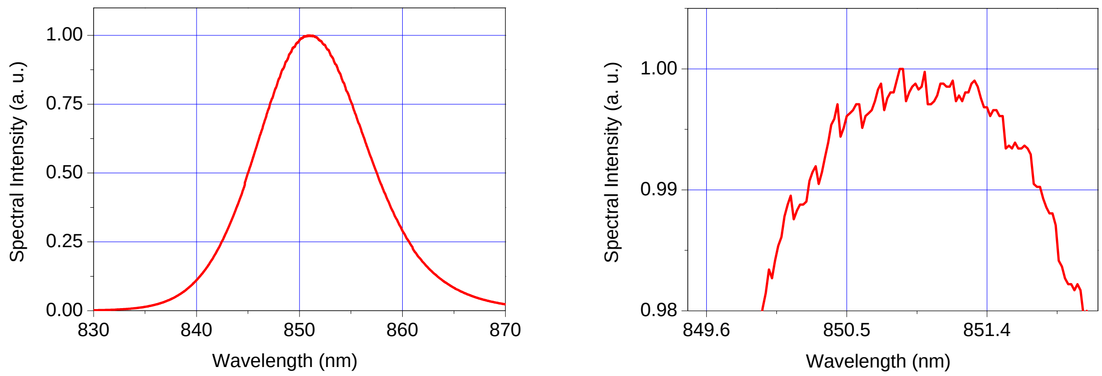

Fig. 4. MOPA spectrum at 50 mW output power (envelope and detailed).
Measurement resolution better than 0.02 nm. Spectral ripple < 0.5% (0.02 dB) on top.

Next figures present some important spectral properties of MOPA system.

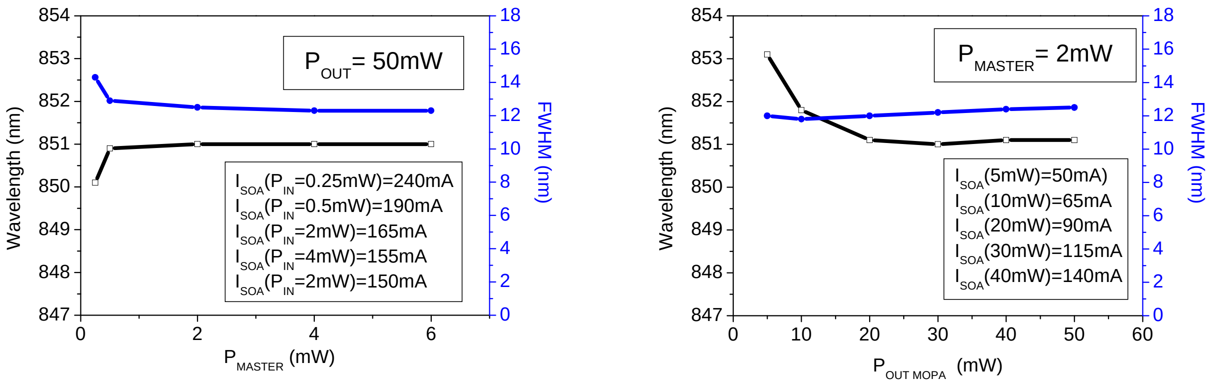

Fig. 5(a) Fig. 5(b)

Fig. 5. Center wavelength and spectrum width of MOPA at different conditions.

Fig. 5(a) shows the dependence of MOPA central wavelength and its spectrum width on power of the master SLD. In this experiment, 5% of MOPA output was decoupled for arrangement of output power control loop. The inset shows MOPA currents required for maintenance of 50 mW output. It is clearly seen that MOPA spectrum does not depend on master power if it exceeds 0.5 mW. It is important that master's spectrum changed considerably when its power changed from 0.5 mW to 5 mW (particularly, its center wavelength shifted by almost 5 nm). It is also seen (fig. 5(b)) that spectrum of MOPA does not depend strongly on MOPA current and power when master's power is constant and MOPA power is more than 20 mW.

Advantages of MOPA configuration

These results demonstrate clearly a great potential of "MOPA" approach for making an ultra-high-power broad-spectrum light sources basing on SLDs and SOAs. The main advantages of MOPA systems are as follows:

- Much less sensitivity to optical feedback in parallel to easier achieving of higher optical powers. It is also very important that "medium" optical feedback of a few percents will not result in immediate decreasing of output power by an order of magnitude and/or failure of a 50 mW-ex-fiber MOPA (contrary to stand-alone SLD modules);

- Much better lifetime should be expected with respect to ultra-high-power "stand-alone" SLDs. It is seen from the fig. 3 that up to 350 mA drive current is required to get 50 mW ASE output power when SOA operates in SLD mode. This current reduces to 150 mA when MOPA power is 5 mW, and to 190 mA when MOPA power is 2 mW. This should result in considerable improvement of lifetime. Preliminary results of lifetime tests show that lifetime exceeding 30000 hours at 50 mW SM-fiber output power is within reach.

We have also successfully reached around 0.5 W ASE power in multimode sources at 840 nm by using the MOPA approach. For this purpose, we coupled master SMF SLD module to a special broad-area SOA module based on broad-area SOA chip (25 µm stripe width) with a SM fiber input and a MM fiber output. Catastrophic optical damage was observed at higher output power. Fig. 6 below shows light-current characteristic of the MM fiber based MOPA system.

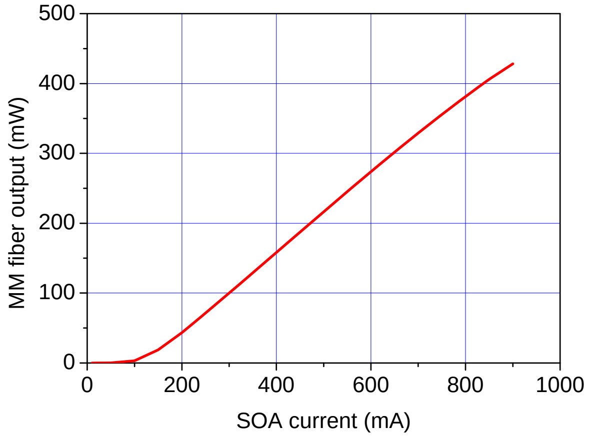

Fig. 6. Light-curent characteristic of MM fiber MOPA SLD light source. Spectrum width is 12 nm.

Output power of 400 mW had been realized in MM fiber. Work on further improvement of such super-high-power wide-spectrum light sources is in progress.

References

1. A.T.Semenov, V.R.Shidlovski, “Very High Power, Broad and Flat Spectrum Superluminescent Diodes and Fiber Modules for OCT applications”, ***BIOS 2000, , Photonics West '99, San-Jose, CA, 24-26 Jan. 2000,*** paper 3915-43.

2. “SLD sensitivity to Optical feedback”, Application note, www.superlumdiodes.com/pdf/sld_feedback.pdf.

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