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Power Scaling of Lasers

R. Paschotta
RP Photonics Consulting GmbH, Waldstr. 17, 78073 Bad Dürrheim, Germany

In the context of high power laser research and development, the term "power scaling" is very often used. However, very frequently this is done without using a clearly defined concept, although such concepts are quite common in other areas of technology such as computing and manufacturing. Correspondingly, the terms "scalability" and "power scaling" are often used in a vague or even meaningless manner. Clarifying such issues can create a lot of important insight.

This course explains power scalability of laser architectures as a precisely defined concept, and demonstrates with a number of examples that this is very useful in particular for evaluating future potentials of various kinds of high power lasers and thus for guiding further research and development. First, sensible criteria for a well-defined scaling procedure are discussed, the existence of which lies at the heart of any true scalability. Such a power scaling procedure describes how to transform an existing and working laser design into another design with e.g. two or ten times the output power. The essential features which must be demanded from a true scaling procedure are the following:

- The procedure must be systematic and well defined. For example, the form of such a procedure could be: For doubling the output power, double the pump power, apply it to twice the mode area in the gain medium, reduce parameter X by one half while keeping parameter Y constant.
- The procedure must be repeatable, allowing to vary the output power in a large range. This requirement has several important implications. In particular, application of the procedure should not spoil essential features of the laser, such as e.g. its power conversion efficiency or beam quality. Also, the procedure must be devised so that enhanced laser designs do not rely on increasingly critical specifications for the components to be used in the laser. Finally, the procedure must not make one or more central challenges, such as e.g. the handling of high optical intensities or strong thermal effects, significantly more severe as the power is increased.

Any laser architecture involves a large number of technical aspects, the scaling properties of which can be separately analyzed. Examples for such aspects are the involved optical intensities, thermal effects, or required pump brightness. Even though scalability of a laser architecture as a whole requires scalability of all such aspects, the study of scaling properties of isolated aspects can produce important insight for essentially any kind of laser. The analysis of current technical obstacles is only a starting point. It is vital to precisely understand (a) the physical details of limiting effects, (b) their impact on the further development (not only how strong they are, but also "how they scale"), and (c) available options to mitigate or eliminate those effects of strongest impact without introducing or exacerbating other problems. For issues (b) and (c), it is essential to recognize the existence or non-existence of a scaling procedure which takes into account the potentially limiting effects.

Plenty of examples can illustrate the usefulness of such thoughts. There are cases where a certain effect is certainly not weak even in low-power laser designs, but nevertheless does not prevent scaling to much higher powers, because a scaling procedure exists which allows to keep the critical parameters under control even at highest powers. A good example for this is the finding that thermal effects in saturable absorbers for passive mode locking, which can be significant even in low power lasers, have not prevented the power scaling over orders of magnitude; not recognizing certain scaling properties was the mistake which previously made many researchers believe that semiconductor absorbers would be unsuitable for high powers, at least with known materials and designs. On the other hand, effects which are negligible in low-power devices can later constitute limits of power scaling. For example, dispersion compensation can be a severe challenge in mode-locked high power lasers, while high power fiber lasers and amplifiers with diffraction-limited output will soon hit limits associated with nonlinearities and optical damage. Another interesting observation is that the power scaling properties of saturable absorbers can be very different for laser devices with high pulse repetition rates, creating a need for substantially revised designs even for much lower power levels than are easily achieved with lower pulse repetition rates.

Such examples convincingly demonstrate that a well-founded analysis of scaling properties is vital for understanding the impact of particular technical problems, assessing the value of proposed countermeasures, and judging the future potentials of different technological approaches. In this way, work on high power lasers can profit from the introduction of clearly defined terms and sensible criteria, and from the concrete analysis of important scaling properties. As a final remark, variations of the concept can be similarly useful for studying the scaling of other quantities than output power, such as e.g. pulse repetition rates of mode-locked or Q-switched lasers.

References

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