WHITE PAPER

How many cavities in your 10 kW laser cutting machines?

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In this article, I share my thoughts on the evolution of the output power of laser cavities, which are nowadays combined to produce a total power of at least 10 kW in industrial metal cutting systems. The focus is on recent advances in Fiber Bragg Gratings (FBG) reflector technology as a key contribution to power scaling of cavities.

The race to cut metal at higher speeds and lower costs is fueling the demand for cost-effective laser systems capable of reliably delivering output power levels above 10 kW with good beam quality. A ubiquitous approach to achieving this goal is to combine the output of near-single-mode (SM) fiber laser cavities into a delivery fiber whose core diameter ultimately determines the beam quality the system can achieve. The industrial laser market is extremely competitive, and every company is looking for opportunities to differentiate itself at the lowest possible cost per W. Profit margins are often shallow, and every single dollar that can be subtracted from the bill of material (BOM) can make the difference between winning a business opportunity or loosing it to a competitor.

Currently, the maximum output power that can be reliably produced for a single cavity is in the range of 2.5 to 3 kW. Therefore, at least four cavities are needed to get 10 kW or more. But the power handling of fiber laser components is continually improving, and the day we see SM cavities with up to 4kW of output power in production may be closer than you think. This means that only 3 cavities will be needed in the near future to produce 10kW or even 12kW systems, allowing a significant reduction in the BOM of the laser system.

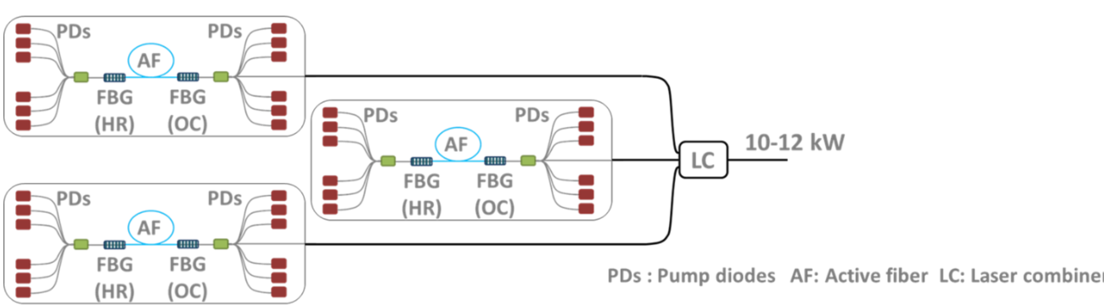

Fig. 1 – The combination of three cavities will soon be enough to produce 10-12 kW.

Laser pumping

Technology for pumping 4 kW cavities is readily available for volume orders. For 976 nm pumping, a total pump power of around 5 kW is needed. For a 50/50 ratio between co-pumping and counter-pumping, 5 to 6 pump modules can be combined on each side of the cavity. It is in principle advantageous to use a backward pumping ratio (defined as the counter-pumping power divided by the total pumping power) greater than 50% to suppress Stimulated Raman Scattering (SRS), as long as the backward pump combiner and the cavity output coupler (OC) can handle it.

Optical fiber

Passive and active 3 kW-class double clad LMA fibers are now available on the market. 3 kW cavities are becoming reality on a larger scale, with a quick learning curve of how to build a cavity with sufficient headroom to avoid instabilities or other limitations due to SRS and/or Transverse Mode Instability (TMI). Reducing photodarkening has been instrumental in increasing the TMI threshold, and LMA fibers rated at 3.5 kW or even 4 kW are likely the next step as fiber technology continues to improve.

Fiber Bragg grating (FBG) reflectors

Recent advances in FBG reflector technology allow higher power handling with superior reliability, competitive prices and shorter lead times. The reliability of FBGs is mainly influenced by the following factors,

- Number of manufacturing steps
- Manufacturing process quality and consistency
- Degree of preservation of the pristine fiber integrity
- Operating temperature in the laser

whereas the FBG price mainly depends on,

- Number of manufacturing steps
- Manufacturing process yield
- Degree of process automation

The traditional FBG manufacturing process involves many steps, including window stripping of the polymer coating, sensitizing the fibers (usually takes several days), FBG inscription with a UV laser, FBG stabilization, desensitization of the fibers (several days) and FBG recoating. 3 kW-class FBGs can be produced with this process, but beyond this power level it becomes much more difficult to achieve acceptable yields without sacrificing component reliability. The process window becomes very narrow, which often means a transition to a cherry picking mode. The many steps of the traditional risk compromising the integrity of the fiber and therefore the reliability of the FBG. Window-stripping the fiber inherently means that the integrity of the fiber is not preserved. As power increases, imperfections that could once be tolerated produce temperature rises that now exceed acceptable limits.

A new process now alleviates these limitations. It is the best FBG solution towards large scale deployment of reliable laser cavities beyond the 3 kW mark. The Write-Through-Coating (WTC) process relies on a femtosecond laser to write FBGs without sensitization nor stripping of the fiber. This represents huge advantages over the traditional process. The key is that the refractive index modification that is required to write a FBG is realized through a nonlinear interaction occurring in a very small volume within the bulk of the fiber. This intensity is reached by focusing the laser beam into the core of the fiber while maintaining a safe level of intensity at the polymer coating.

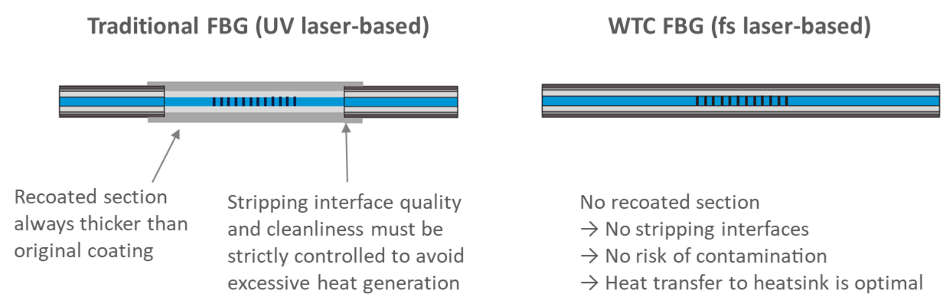

Fig. 2 – Compared to traditional FBGs, WTC FBGs are more suitable for cavity power scaling beyond 3 kW.

Preserving the polymer coating helps prevent the creation of defects that act as heat generating centers. In addition, the absence of recoat ensures that thermal resistance is not increased at the location of the FBG (recoated sections are always thicker than the original coating of the fiber). Figure 3 shows the predictions of an analytic model based on the heat equation on the theoretically achievable cavity output power with UV vs WTC gratings, as a function of the backward pumping ratio. The model considers the contribution of pump and signal power adding up to produce a maximum allowable temperature rise of fluoroacrylate of 15°C for typical FBG packaging conditions. No other limitation (such as SRS and TMI) is taken into account by the model.

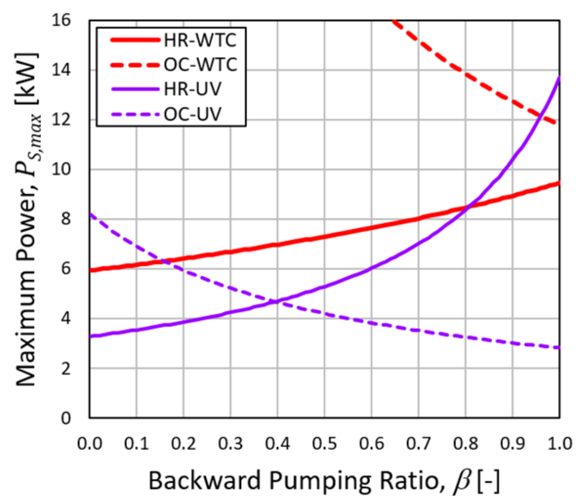

Fig. 3 – Theoretical limit of cavity output power vs backward pumping ratio for traditionnal (UV) and WTC FBGs .

As shown in the graph of Figure 3, the OC is the limiting factor for UV gratings, and achieving good yield and reliability as the output power approaches 4 kW will be very challenging, if not out of reach. The WTC OC heating is much lower, hence the theoretical limit of 12 kW. The WTC HR limit exceeds 6 kW. Thus, overall, WTC gratings offer significantly higher power handling for a given fluoroacrylate temperature criterion. And for a given output power level, WTC gratings can operate at significantly lower temperatures (especially OCs), which promotes superior long-term reliability. The very low temperature rise of the OC also provides more leeway to limit the SRS by choosing a backward pumping ratio higher than 50%.

In addition to the advantages mentioned above, it can be added that the reduced number of manufacturing steps of the WTC process allows high throughput automation of FBG manufacturing. This favor shorter delivery times and more aggressive prices.

Conclusion

The evolution of the technological building blocks of multi-kW industrial fiber lasers makes it possible to envisage in the short term a reduction in the BOM of 10+ kW laser cutting machines through a reduction in the number of cavities required. This includes new FBG reflector technologies written with femtosecond laser, which not only allow more power but also ensure superior reliability while maintaining a competitive price.

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