Fiber laser processing of highly reflective materials

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Laser processing of highly reflective materials is increasingly important in modern manufacturing. Many laser technologies, however, suffer from inherent sensitivity to back-reflected light, which can cause process instability, disruptive shutdowns, or even catastrophic failure of the laser. A new generation of fiber lasers addresses these limitations with high-performance components and a novel architecture that enables uninterrupted processing of highly reflective materials (Fig. 1).

Figure 1. nLIGHT alta™ industrial fiber lasers – From left to right, rack-mounted unit from 500 W to 1.2 kW, rack-mounted or stand-alone unit from 1.5 to 2.5 kW, stand-alone chassis from 2 to 4 kW, and stand-alone chassis from 6 to 8 kW.

Back-reflection isolation

Even for highly reflective materials, typical back-reflections are only a fraction of the laser output power because of work-piece surface irregularities, displacement of the back-reflecting surface from the beam waist, lack of precise alignment with the surface normal, and the limited collection angle of the process optics; furthermore, in many cases the back-reflection has a short duration (e.g., during piercing). Nonetheless, the design of some fiber lasers results in high sensitivity to back-reflections, resulting in laser instability or damage. Some fiber lasers employ software protection that disables the laser in the case of a back-reflection; this approach may protect the laser in some situations, but it precludes successful continuous material
processing. Back-reflection sensitivity thus renders processing of reflective materials or surface finishes difficult or impossible.

Several mechanisms can cause damage from back-reflections. A common mechanism is deposition of optical power into polymer materials, which overheat and burn. All nLIGHT alta™ fiber lasers (Fig. 1) include a robust integrated back-reflection isolator. This isolator strips the back-reflected light coupled into the feeding fiber and directs it to a water-cooled beam dump where it is converted to heat without any interaction with polymers, thereby eliminating the primary damage mechanism. The polymer-free isolator is designed to dump >1000 W continuously. The design was validated by a high-stress life test, in which 100% of the output of an nLIGHT alta™ 1 kW fiber laser was back-reflected into the laser using a mirror. Despite this extreme level of back-reflection, the laser operated without any instability, damage, or shut-offs for >100 hrs. (Fig. 2a). We know of no other laser that has been subjected to this level of back-reflection without damage.

We evaluated the performance of the isolation system in repetitive piercing tests (piercing is the portion of the cutting process that generates the highest back-reflection levels). In this test, 5000 consecutive pierces of copper were performed successfully with no interruptions or failed pierces (Fig. 2b). Numerous other real-world tests have demonstrated the efficacy of our back-reflection isolation system, and nLIGHT alta™ fiber lasers are now widely used to enable stable, uninterrupted processing of highly reflective materials (Fig. 3).

Figure 2. (a) A continuous laser stability stress test with >1000 W reflected back into the laser for >110 hrs. without any indication of unstable operation or damage. (b) Customer test of copper piercing with a 3 kW nLIGHT alta™ fiber laser. The laser performed 5000 pierces in rapid succession with no process interruptions or failed pierces.
Figure 3. Examples of material processing enabled by the back-reflection insensitivity and stability of nLIGHT alta™ fiber lasers. (a) Copper cutting samples. (b) Deep-penetration copper welds. (Image provided by Laser Depth Dynamics)

Highly reflective cutting results

Sheet metal cutting is the largest market for kW fiber lasers. Applications in the automotive, aerospace, and electronics industry, such as production of lightweight components and lithium-ion battery cells, are moving towards the use of highly reflective materials, such as aluminum, brass, copper, stainless steel (including mirror stainless steel), silver, and gold. Sheet metal cutting typically generates back-reflected light in short bursts when piercing (~1 ms) or during process excursions, such as loss-of-cut or out-of-focus situations. Using back reflection sensors internal to the nLIGHT alta™ fiber lasers, the amount of back reflected light can be observed on different metal types as shown in Figure 4.
Figure 4. Example of the signal from laser light back-reflected from the work piece when piercing stainless steel, aluminum and copper sheet metal as detected using sensors in side of the nLIGHT alta™ product.

Use of legacy fiber lasers in these applications has been limited by back-reflection sensitivity. In contrast, nLIGHT alta™ fiber lasers have successfully cut a number of reflective materials, including aluminum, copper, brass, gold, silver, and mirror finish metals without laser instability or damage and without process interruptions. Example cutting speed performance is shown in Fig. 5 for pure (101) copper (Fig. 3a shows example parts). Stable processing up to 12 mm thick has been demonstrated. Figure 6 shows representative cutting samples in some of the other materials of interest.

![Copper Cutting Speed Graph](image)

Figure 5. Example cutting speeds for 1 kW, 3 kW, and 6 kW nLIGHT alta™ lasers on pure copper samples.
Highly reflective welding results

Welding generates more sustained back-reflections than cutting when the laser beam does not fully penetrate through the work piece. nLIGHT alta™ fiber lasers have been used for welding a plethora of alloys including aluminum, brass, and copper, without exhibiting laser instability or damage, even while welding at normal incidence. The images in Figs. 3b and 7 show examples of copper welding, a particularly challenging application that has caused significant damage to other fiber lasers.

Figure 6. Cutting samples (a) aluminum, (b) silver, (c) brass, and (d) mirror finish stainless steel.
Figure 7. Welding samples; clockwise from top left, example of bronze (C51900) weld seam and its cross-section, example of pure C10100 copper weld seam and its cross-section.

Another important process is stir welding of pure copper using a scanning mechanism. Figure 8 shows an example performed with a single-mode 1 kW fiber laser with only linear motion. In this case, pores are clearly visible on the top surface of the weld. By scanning a small spot in a spiral pattern (Fig. 9), the weld is far more stable than a weld performed without scanning as exhibited by the bead consistency and lack of pores. Both welds were produced at the same linear velocity (50 mm/sec).

Figure 8. Single-mode 1 kW welding of pure copper at 50 mm/sec – weld surface photo and cross section showing porosity, blow outs, spatter and weld instability.
Figure 9. Single-mode 1 kW welding of pure copper at 50 mm/s with beam stirring – weld surface photo and cross section demonstrating process stability, lack of porosity, and consistent weld shape.

Conclusion

The nLIGHT alta™ next generation fiber laser offers a revolution in kW laser materials processing, particularly for reflective materials and finishes that could not be processed by legacy fiber lasers because of innate limitations of their designs and their approaches to back-reflection protection. By demonstrating stable piercing, cutting and welding of these materials without any process interruptions or laser failures, the nLIGHT alta™ fiber lasers open the door for reflective material processing in progressive automotive, aerospace, electronics, and consumer goods applications.

Contact:

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References