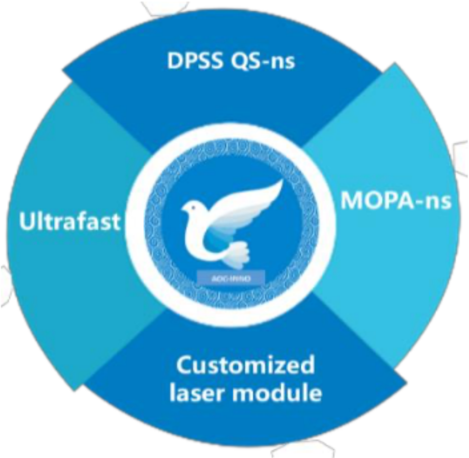
Femtosecond Laser Stent Cutting



About Us

Industry Laser Solution Provider

AOC's strategic emphasis lies in laser and laser application R&D, global sales and marketing endeavors, and the provision of localized customer service and support.

AOC laser product portfolio consists of a broad spectrum of pulsed lasers, including DPSS QS-ns lasers, ultrafast lasers, and MOPA-ns lasers, covering different wavelengths from IR to DUV, and different pulse widths from nanosecond, picosecond to femtosecond. Combining the innovative laser technologies with laser process development capability, AOC can offer complete laser application solutions. With advanced optical design, vision system, motion control system and self-developed software, AOC is now supplying laser micro-processing systems.

AOC products strongly enhance our customer's capabilities and productivity in consumer electronics, biomedical applications, semiconductor, and other areas. As of today, there are tens thousands laser source and micro-processing system in use in these application fields.

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Stent applications and fabrications

A stent is a specialized medical device designed to provide structural support and maintain the patency of various vessels and tubular structures within the human body. Widely utilized in the medical field, stents play a crucial role in the intervention and management of conditions characterized by the narrowing or obstruction of arteries, veins, and other bodily passageways. Table 1 outlines essential aspects related to the application of stents, encompassing key considerations in their deployment and impact on patient care.

Table 1. Application of medical stents
1. Coronary Artery Stent: Treating coronary artery disease by keeping the arteries open after balloon angioplasty. Drug-eluting stents release medication to prevent restenosis (re-narrowing) of the treated area.
2. Peripheral Artery Stent: To open narrowed arteries in the legs or other peripheral regions.
3. Biliary and Gastrointestinal Stents: To treat blockages or strictures in the bile ducts or gastrointestinal tract.
4. Ureteral Stents: To maintain urine flow and prevent obstruction.
5. Tracheobronchial Stents: To keep the airways open in the treatment of conditions.
6. Vascular Stents: Applied in various blood vessels to treat stenosis or other issues affecting blood flow.

Two primary categories of medical-grade materials are frequently employed as base materials for stent devices. The first category comprises medical-grade metals which are prevalent, while the second involves medical-grade biodegradable polymers which are in special application only. Table 2 provides a comprehensive overview of major materials used in stent fabrication, including their advantages.

Table 2. Overview of materials used for stent		
1. Metals	Stainless steel	(i) Well-established; (ii) Relatively low cost. (iii); Good mechanical properties; (iv) Lower flexibility
	Ni-Ti alloy (Nitinol)	(i) Excellent flexibility and shape-memory properties; (ii) High resistance to corrosion; (iii) Higher cost; (iv) Limited visibility for certain imaging techniques.
	Co-Cr alloy	(i) Good strength and corrosion resistance; (ii) Better visibility under X-ray imaging; (iii) Less flexible; (iv) Higher cost.
	Mg-alloy	(i) Biodegradability; (ii) good mechanical properties; (iii) Rapid corrosion; (iii) Degradation
2. Polymers	PLA/PLLA	(i) Biodegradability; (ii) versatility in stent design; (iii) Lower mechanical strength & stiffness; (iv) Degradation Rate Control

In contrast to conventional tubing cutting methods, which typically involve removing only a small fraction of the base material, stent cutting is a specialized process that necessitates the removal of over 80% of the base material to form a designed network. As such, stent cutting is recognized as a distinctive and specialized technique in the field of tubing fabrication.

Laser Stent Cutting Technology

After decades of advancements in laser cutting technology, the laser cutting of stents has evolved into the industry-standard process. Initially, nanosecond infrared (ns-IR) fiber laser cutting dominated the scene due to its cost-effectiveness and excellent reliability. However, fiber laser processing has a significant drawback — the generation of substantial molten material, necessitating a complex post-cleaning procedure.

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The emergence of cost-effective femtosecond (fs) lasers at an industrial level has sparked a revolution in stent cutting, particularly with the introduction of "cold processing." This innovation enables the efficient processing of stents, especially those made from low-melting materials such as magnesium or polymers. Figure 1 illustrates the direct cutting of PLA using a fs-IR laser, followed by a simplified cleaning procedure.

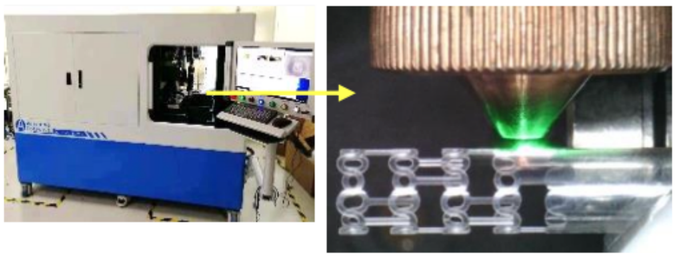

Fig.1 fs-515nm laser cutting PLA stents.

Figure 2 depicts a process comparison between stent cutting utilizing a fiber laser and fs-laser, respectively.

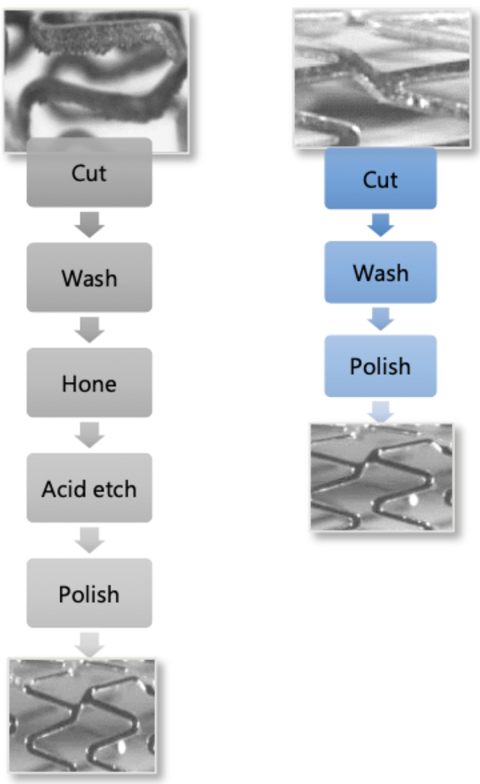

Fig.2. Comparison of fiber-laser and fs-laser cutting metal stents and sequential post-treatments

The tubing cutting parameters for fs Laser are subject to variation depending on the material type, tube wall thickness, and specific cutting features. Table 3 provides a summary of the parameters applicable to tubing with a wall thickness ranging from 0.1mm to 0.3mm. These parameters were formulated by AOC Apps Lab, utilizing AOC's fs-1030nm/515nm Dura-wavelength laser, as depicted in Figure 3.

Table 3. Major fs-laser cutting parameters

Material	Wavelength	Pulse energy	Protection gas
Stainless steel (SUS)	1030nm	1-3uJ/p	Ar, He
Ni-Ti alloy	1030nm, 515nm	1-3uJ/p	Ar, He
Co-Cr alloy	1030nm	1-3uJ/p	Ar, He
Mg alloy	1030nm/ 515nm	1-3uJ/p	Ar, He
PLA	515nm	0.2-1uJ/p	N2
PLLA			

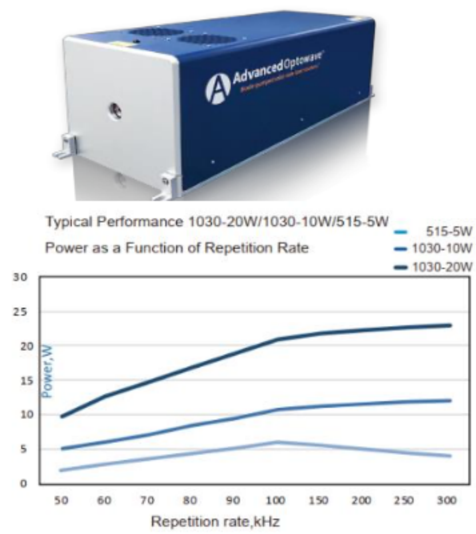

Figure 3. AOFemto Jericho series industrial 1030nm/515nm fs laser

Laser Stent Cutting Examples

With nearly a decade of dedicated collection efforts, AOC has successfully developed an fs-laser stent cutting technology that is widely recognized in the industry.

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Having served numerous clients in the medical device industry, this article aims to showcase actual examples of stent cutting. Through these illustrations, readers can gain insights into AOC's stent cutting capabilities and the quality of their work.

1. Stainless-steel stent (SUS). SUS stands out as one of the most popular and well-established medical-grade metals employed in stent fabrication. Its exceptional material uniformity, cost-effectiveness, and tubing quality contribute to its widespread use. In Figure 4, scanning electron microscope (SEM) images depict a section of a SUS stent cut using AOC's fs-IR laser technology, followed by a wet-cleaning process in an ultrasonic bath. It's important to note that the stent features presented in the images are self-designed for demonstrative purposes.

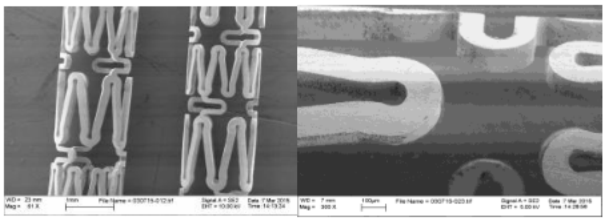

Figure 4. SEM images of SUS stent cut by fs-1030nm laser followed by standard post-cleaning procedure.

Although the fs-laser cut feature seemingly presents no observable damage, electron polishing (EP) is employed to remove a surface layer in a range of a few um or less. This process ensures the elimination of any hidden damage that may not be apparent (in Figure 5).

Figure 5. Optical microscope image of EP treated SUS stent cut by fs-laser.

2. Ni-Ti alloy (Nitinol). Ni-Ti alloy stands out due to its superior flexibility, corrosion resistance, and remarkable shape memory properties.

These unique characteristics make Nitinol stents particularly valuable in medical applications involving small and tortuous vessels, where their ability to flex and conform is crucial. Figure 6 showcases optical microscope images of the stent, precisely cut using the AOC fs-1030nm laser. The images highlight a clean-cut edge and surface, underlining the precision and quality achieved through this cutting method.

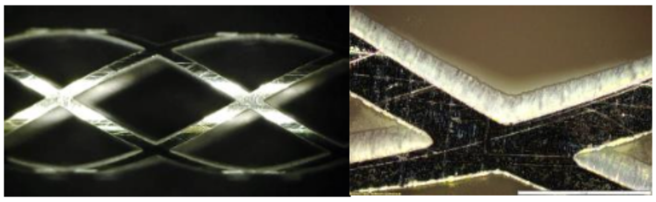

Figure 6. Optical microscope images of Nitinol stent cut by fs-1030nm laser followed by standard post-cleaning

3. Co-Cr alloy. The Co-Cr alloy stent stands out due to its exceptional properties, including remarkable biocompatibility, high strength, and notably, enhanced visibility during X-ray imaging. Nevertheless, achieving a superior-quality Co-Cr alloy stent requires a more intricate processing approach. In Figure 7, SEM images depict a Co-Cr stent section cut using a fs-1030nm laser following a standard wet-cleaning procedure in an ultrasonic bath. Subtle deposits are noticeable on the cut surface, necessitating the application of electropolishing (EP) for thorough cleanup.

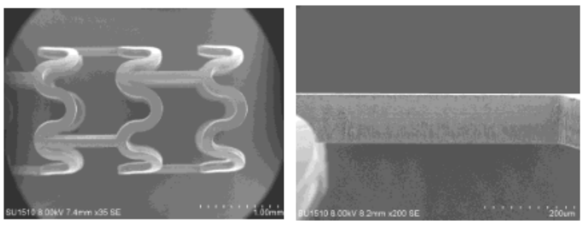

Figure 7. SEM images Co-Cr stent cut by fs-1030nm laser followed by standard post-cleaning procedure.

4. Mg alloy stent. The Mg alloy stent is of particular interest because of its potential to degrade over time, addressing the issue of long-term foreign material presence in the body. However, it is currently in the development phase and undergoing clinical trials, primarily due to safety concerns.

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Unlike other metals, the use of fs-Laser is imperative to prevent the burning of Mg, given its highly flammable nature. Figure 8 displays SEM images illustrating a section of a Mg alloy stent cut using a fs-1030nm laser without post-treatment. The images showcase exceptional quality, notably featuring a clean-cut surface.

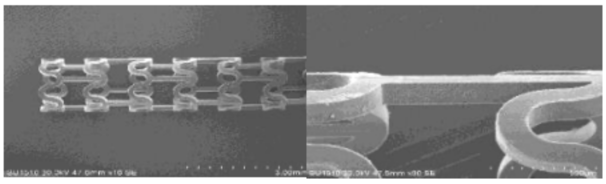

Figure 8. SEM images of Mg alloy stent cut by fs-1030nm laser

5. PLA stent. One of the key advantages of PLA stents lies in their biodegradability, where the material gradually dissolves over time, eliminating the necessity for a permanent implant. Consequently, PLA stents are designed to offer temporary support to the blood vessel during the initial healing phase following a stent procedure. As the stent degrades, the vessel can naturally regain its functionality. However, it's important to note that PLA stents are still in the research and development phase. Challenges include the precise control of the degradation rate, maintaining mechanical strength, and minimizing potential adverse effects.

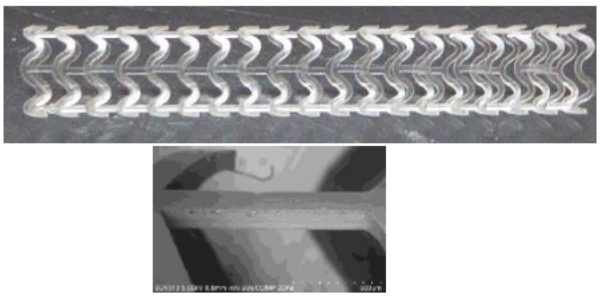

Figure 9. Optical microscope images of PLA stent cut by fs-515nm laser.

Figure 9 presents an optical microscope image at low magnification and SEM image at high magnification, providing a detailed view of a section of a PLA stent cut with a fs-515nm laser without post-treatment. The images clearly demonstrate a precise and clean cut, with no discernible signs of melting.

After a decade of collaborative endeavors, AOC has successfully engineered an advanced industrialized solution for stent fabrication, catering to the needs of medical device customers. This comprehensive solution spans laser manufacturing, process development, system manufacturing, and contract manufacturing. AOC's successful approach signifies a significant milestone in the field, providing a streamlined and efficient process for the production of high-quality stents to meet the demands of the medical industry.

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