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Investigating the Effects of Fiber Laser Surface Treatment on the Hardness and Machinability of 316L and Ti-Zr Implant alloys manufactured through powder metallurgy

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Abstract:
A high-power fibre laser is used to the alloy surfaces as part of the experimental methods to cause controlled microstructural alterations. Comprehensive investigations are then carried out to determine how the laser treatment has affected the material's properties. These analyses include microhardness testing and machinability assessments. The outcomes show significant improvements in both alloys' hardness and machinability, suggesting that fibre laser surface treatment is a feasible method for enhancing the mechanical properties of implant materials made via powder metallurgy. The results of this investigation provide significant contributions to the design and manufacturing processes of implant alloys, with potential to enhance the long-term stability and functionality of biomedical implants.

Key words:*Powder metallurgy,316L stainless steel, Ti-Zr alloy,Hardness enhancement,Machinability improvement,Biomedical applications*

Introduction:

The search for improved mechanical characteristics in implant alloys is still a vital undertaking in the field of biomaterials. The performance, endurance, and biocompatibility of alloys—especially those used in implants—have been carefully considered during the research. Surface treatment procedures are one of the many approaches used to refine an alloy; they are a promising way to modify the mechanical characteristics of materials at micro structural level. The transformative impacts of fibre laser surface treatment on two critical implant alloys—316L stainless steel and Ti-Zr—both of which were created via powder metallurgy are the subject of this study.
The two alloys under study—316L stainless steel and Ti-Zr—represent two different implant material classes. The former is a popular austenitic stainless steel that is known for being biocompatible and resistant to corrosion [9, 10]. In comparison to traditional titanium alloys, the latter, a titanium-zirconium alloy, has favorable mechanical properties. [1] But both alloys provide room for improvement when it comes to hardness and machinability, two important factors that affect how well they function in vivo.The development of better functional connection, or osseointegration, between tissue and metal surface is essential to the functioning of implants. [2]
The primary material utilised in the production of dental implants is titanium alloy because of its superior mechanical qualities and biocompatibility.[3,4] These days zirconium (Zr) and alloy of titanium-zirconium

(Ti-Zr), have been proposed as titanium substitutes due to ongoing technical advancements. [5, 6]The Ti-Zr alloy was created by combining a Ti alloy with 13–15% Zr. Compared to titanium alloys, this alloy exhibits higher mechanical resistance and comparable bone tissue biocompatibility. [6] This characteristic makes the Ti-Zr alloy the preferred material to utilise when creating small-dia implants, particularly in areas with severe occlusal overload. [7, 8] Moreover, it is notable for its compatibility with the titanium alloys' surface treatment.A wide range of industrial industries use 316L and its derivatives because of its high strength-to-weight ratio, less thermal conductivity with lower density, enhanced toughness, and better corrosion resistivity. [11]. Electric discharge machining (EDM) and other non-traditional machining methods are used to handle these difficult alloys. [12, 13], ultrasonic machining [14], electrochemical machining [15], LAM [16], PAM [17], and UAM [18]. Laser beam machining (LBM) is a force-free machining method that may be used to generate different dimensional features in a variety of materials. The impact of the LBM process settings on several machining properties, including the surface roughness and material removal rate, is examined in this paragraph. The two main objectives of laser machining are to reduce surface roughness and increase MRR.The most important variables influencing the MRR and surface roughness of milled alumina ceramic surfaces are excessive laser intensity and pulse overlapping. Using a tighter hatch distance and a slower scan speed can help raise the MRR. The MRR is also significantly influenced by the scanning speed, current, and pulse frequency. Additionally, the laser-machined surfaces' microstructure is crucial for material ejection and material removal rate. Ultra short laser pulses are another potential solution for precision machining. Studies show that femtosecond lasers have a higher MRR than picosecond lasers. It has been suggested that the ideal set of laser parameters will maximise micro-machining quality and MRR. The optimal parametric combination for the lowest MRR and highest surface roughness was developed by Williams et al. [19].

Materials and method:

Particle sizes of 45–100 microns were observed in the extra pure zinc streate (99.99% pure), 316L surgical grade (99.99% pure), titanium powder (99% pure), and YSZ (99.99% pure) that were purchased from NANOCHEMAZON Pvt Ltd.In this work, nine samples of 316L stainless steel (surgical grade) and nine sample of Ti-Zr alloy was taken for experimentation. zinc-stearate, and 99.99% pure ethanol used as binder. Nine 316L and Ti-Zr samples each, produced using a powder metallurgy technique with a compaction load of 750 MPa and a two-hour sintering temperature of 1120 °C, were used in the experiment. 316L steel samples are made up of 99.4% 316L steel and 0.6% Zn striate, while Ti-Zr samples are made up of 85% titanium and 15% zirconium.

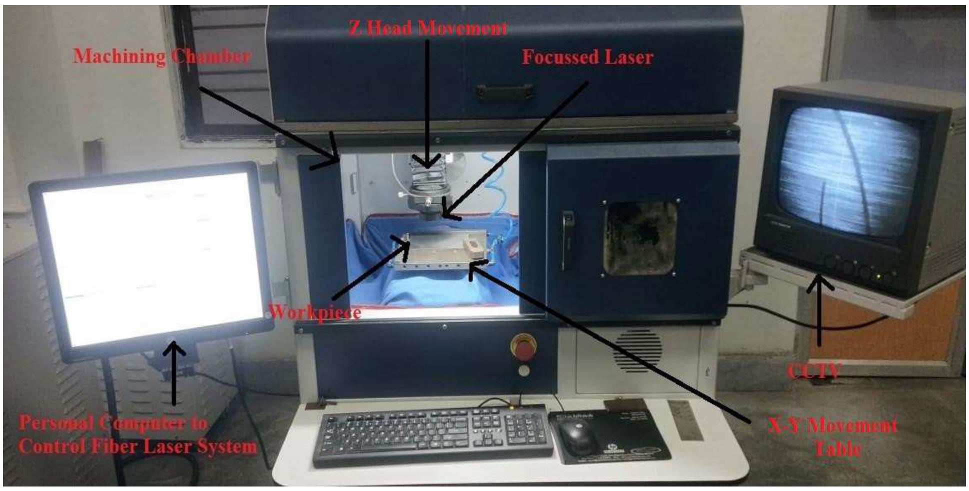

Figure-1: The photographic view of the multi diode pumped pulsed fibre laser system

The Model-Scribo-SLF, a multi-diode pumped Ytterbium doped fibre laser micro-machining system with an average power of 100W, manufactured by M/S Sahaj Anand laser Technology, Pune, India, was used for all of the tests. Figure 1 shows a photographic representation of the multi-diode pumped pulsed fibre laser system utilised in this experiment. A fibre laser is made up of several parts, including an optical fibre, diode pump sources, ions from rare earth materials doped in the fibre, several mirror types, a collimator, and a fibre coupler. A fibre laser operates at a wavelength of 1064 nm. The laser's interaction with the optical fibre material relies on several factors including the laser source and the material's properties. Enhancing the optical characteristics can be achieved through doping with ytterbium Yb3+, a rare earth element.

MRR = (D x W x F / 1000) cc/min. Where: D: Depth of cut in mm, W: Width of cut in mm.F: Feed rate, mm/min. for calculation we have taken {(final value – Initial value)/time } x 1000.

Result and Discussion:

With regard to hardness as was previously mentioned, each sample's hardness is calculated by averaging indentations at a minimum of eight different locations. Table 1 and 2 lists the detailed calculations and information for each sample.Andfigure 2 and 3 shows the surface of the specimen where LBM were. The Taguchi method was used for experimental analysis.

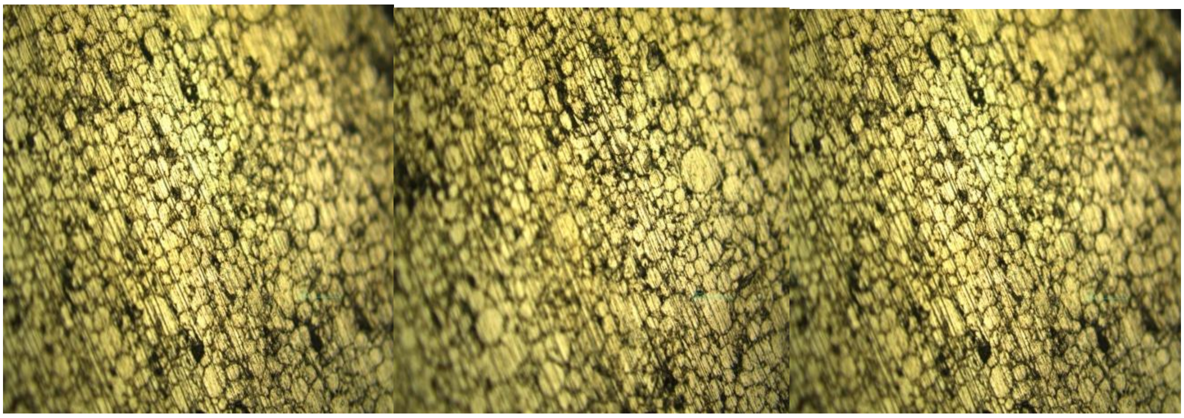

Figure :2 micro scopic image of 316 L samples

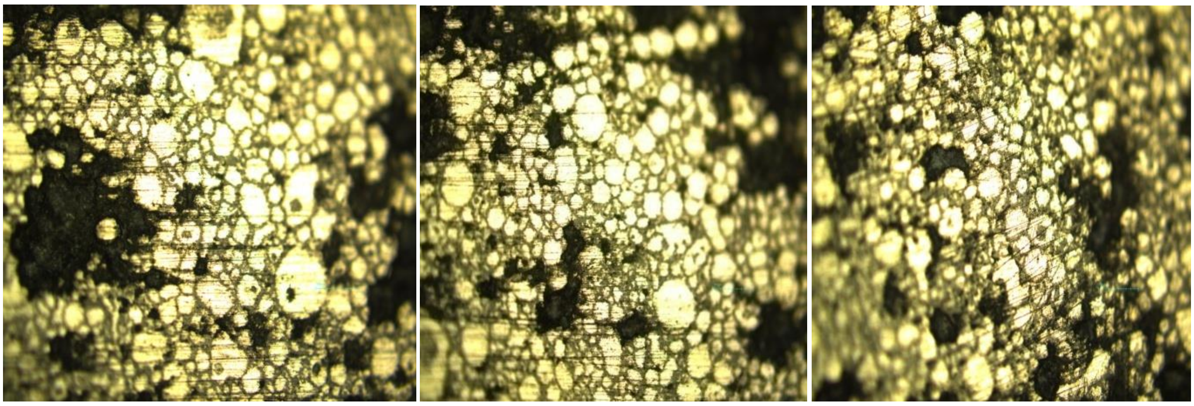

Figure 3 micro scopic images of Ti-Zr samples

Table-1: Results of 316L after LBM

SampleNo.	HARDNESS(HV)		MRR (mm- gm/s)	FREQUENCY (Hz)	POWER (Watt)	CURRENT (Amp)
	LASER SIDE	NO LASER				
1	277	300	0.0375	10	4	2
2	305	300	0.0033	15	4	5
3	330	300	0.0033	10	3	3
4	351	300	0.0067	12	4	3
5	375	300	0.0025	12	3	5
6	345	300	0.0067	12	5	2
7	505	300	0.0012	10	5	5
8	468	300	0.0033	15	3	2
9	526	300	0.0375	15	5	5

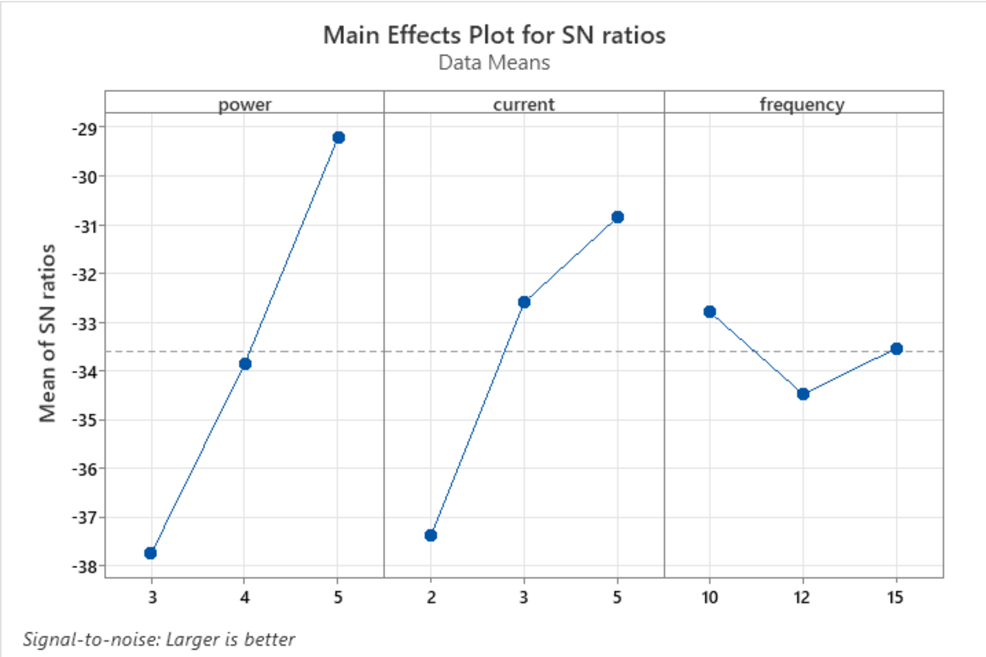

Figure -4: MRR versus Frequency, Power, Current

Form the figure 4 it is seen that micro hardness is increasing with the increase in laser power, current and pulse frequency in a constant scanning speed. It is evident that increased heat changes the mechanical properties of the material by increasing hardness and wear resistance.

This phenomenon is frequently linked to heat treatment procedures, which modify a material's properties by carefully regulated heating and cooling. In this instance, it is clear that the higher heat from the laser processing is affecting the microstructure of the material, leading to increased hardness and enhanced wear resistance. These discoveries may have ramifications for a number of applications, including surface hardening and altering material characteristics to meet certain functional needs. These findings may be verified by more analysis and thorough research, which could also result in a deeper understanding of how material behaviour and laser settings are related.

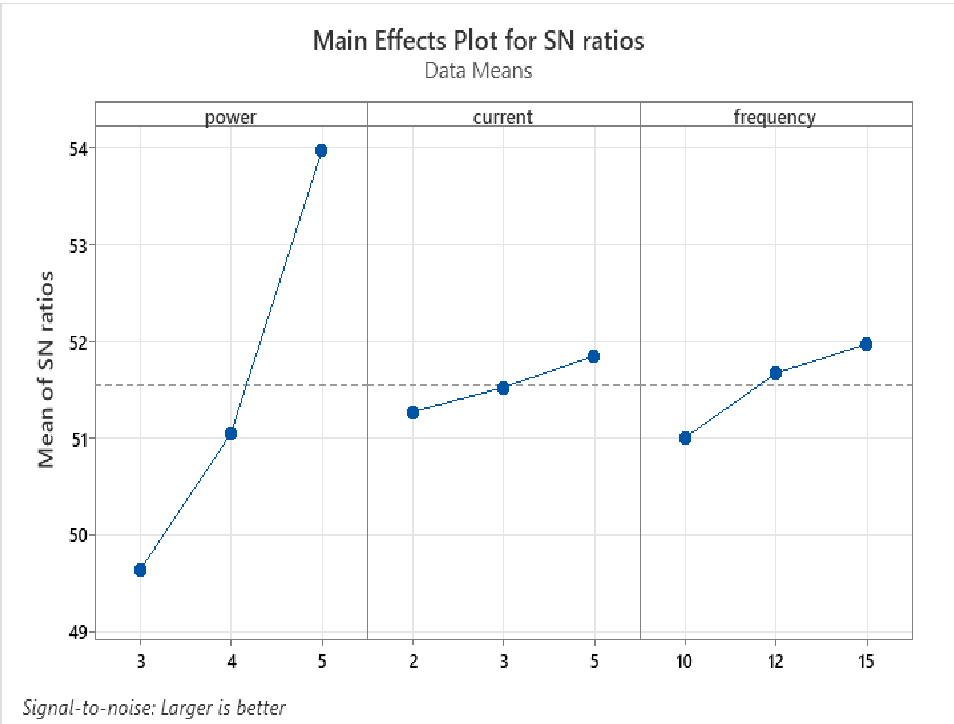

Figure-5: Hardness Versus Frequency, Power, Current

Form the figure 5 it is seen that micro hardness is also increasing with the increase in laser power, current and pulse frequency in a constant scanning speed. It is evident that increased heat changes the mechanical properties of the material by increasing hardness and wear resistance.

This data implies that the material's microstructure is directly impacted by the heat produced by the laser processing, leading to increased hardness and wear resistance. Understanding and optimising laser processing conditions for particular purposes, such boosting a material's mechanical performance or durability, can be greatly aided by this association between laser parameters and material attributes. These findings may be verified with additional research and experimentation, which will also provide light on the underlying mechanisms.

Figure 4 shows that as laser power, current, and pulse frequency are increased while maintaining a constant scanning speed, micro hardness rises. The increased heat produced during laser processing is the cause of this rise. We can now establish a correlation by looking at Figure 5, which likewise displays an increase in micro hardness. The assumption that higher laser power, current, and pulse frequency result in higher heat levels during laser processing is further supported by the pattern shown in Figure 5. It is then determined that one of the main factors influencing the material's mechanical properties is this increased heat.

Thus, the following is how we might correlate the findings: The trend in Figure 5 and the increase in micro hardness seen in Figure 4 support the idea that heat generated by higher laser power, current, and pulse frequency is a major factor affecting the material's mechanical properties. This association implies that the changes in material hardness and wear resistance that follow from the selected laser parameters are directly related to each other.

Table-2: Results of Ti-Zrafter LBM

Sample No	HARDNESS (HV)	MRR (mm-gm/s)	FREQUENCY (HZ)	POWER (Watt)	CURRENT (Amp)
1	412	0.221	12	6	3
2	415	0.294	16	5	6
3	305	0.252	14	4	4
4	353	0.203	16	5	4
5	315	0.226	14	4	6
6	312	0.196	12	6	3
7	409	0.162	12	4	6
8	285	0.175	14	6	3
9	320	0.177	16	5	6

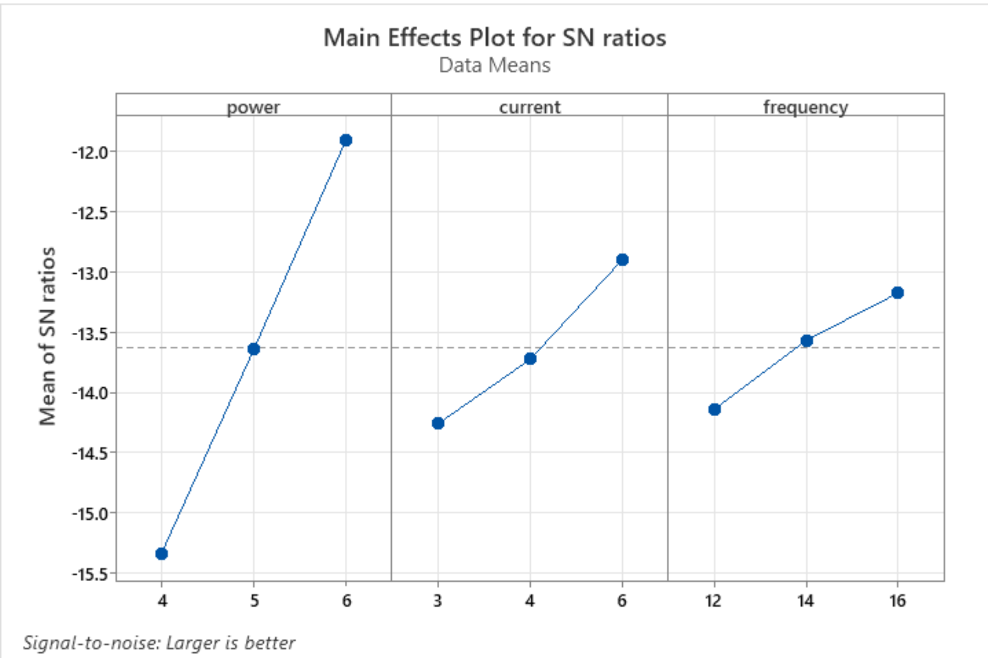

Figure- 6: MRR versus Frequency, Power, Current

The Material Removal Rate (MRR) is seen to be trending upward as laser power, current, and frequency increase in Figure 6. It is true that larger temperatures are produced by high energy inputs, such as those caused by increasing laser power, current, and frequency. This is connected to a rise in MRR in turn.

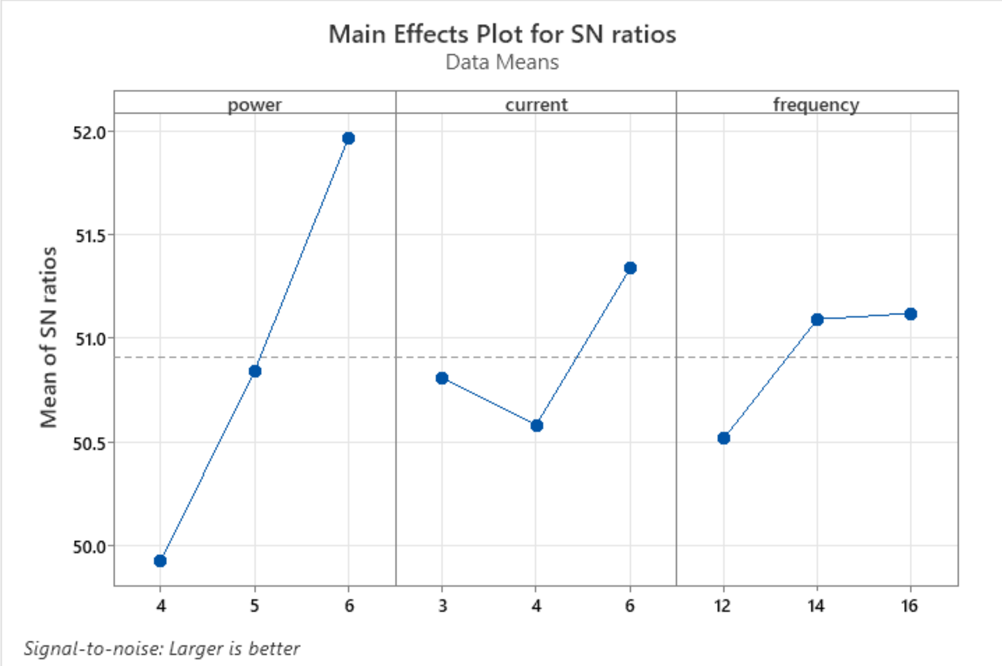

Figure- 7: Hardness versus Frequency, Power, Current

According to Figure 7's observations, Material Removal Rate (MRR) shows an increasing trend as laser power and frequency increase, with current having a relatively little impact. As you accurately point out, higher energy—produced by higher laser power and frequency—leads to higher temperatures, which in turn raise MRR.

The Material Removal Rate (MRR) shows an increasing trend with higher laser power and frequency in Figures 6 and 7. These trends are similar, indicating a strong relationship between higher energy inputs (from higher laser power and frequency) and improved MRR. But the influence of current is where the crucial difference becomes apparent. While Figure 7 indicates that the influence of current is relatively minimal when compared to laser power and frequency, Figure 6 does not specifically address the impact of current on MRR. As a result, Material Removal Rate and laser power and frequency show a positive association, with higher values of these parameters corresponding to higher MRR. Even when current is present, its impact is rather small within the measured range. This correlation offers a thorough grasp of how different laser parameters affect material removal effectiveness in a collective manner during laser processing. Additionally, it highlights the subtle differences in impacts across various factors, with laser power and frequency having a greater influence on MRR.

Conclusion:

In this work, focus on the hardness and machinability of 316L stainless steel and Ti-Zr alloy manufactured through powder metallurgy. And the investigation into the mechanical properties of nine-sample conclude that fabrication of 316L and Ti- Zr is done by powder metallurgy technique successfully.It can be seen that micro hardness rises as laser power current and pulse frequency increases for 316L stainless steel. The hardness increases also with the increase of all three-input parameter. For Ti- Zr alloy, it is seen that MRR exhibits an upward trend with increasing laser power and frequency, although current has very little bearing. Hardness of Ti- Zr alloy is increasing with the increase of power, current and frequency.
These findings collectively provide valuable insights into the intricate relationships between laser processing parameters and material properties. Understanding these correlations is crucial for optimizing laser processing conditions in various applications, including material hardening, wear resistance improvement,

and efficient material removal. Further research and detailed analyses may refine these correlations and contribute to the development of precise laser processing techniques tailored for specific material requirements.

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