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纳秒脉冲光纤激光诱导铝合金等离子体的物理特性

覃禹智，许志颖，张宁，李嘉铭*，马琼雄，郭亮，张庆茂*

华南师范大学，信息光电子科技学院，广东省微纳光子功能材料与器件重点实验室，广东省广州市番禺区外环西路 378 号，510006

华南师范大学，省部共建光信息物理与技术国家重点实验室，广东省广州市番禺区外环西路 378 号理四栋，510006

* jmli@m.scnu.edu.cn; zhangqm@scnu.edu.cn

铝合金具有高强度密度比、低热膨胀系数、导电导热性好、低成本等特点而被广泛应用到航空航天、建筑、交通、和各类生活日常用品的工业生产制造中。随着我国制造业的升级，科学技术水平和工业经济不断发展，不断对铝合金的性能提出了更高的要求。一般的铝合金硬度低、耐磨性差，难以满足日益复杂的工作环境提出的技术要求。通过激光加工改变材料结构和表面可以显著改善铝合金的性能。激光加工过程极快，因此对其加工情况进行实时监测和表征十分困难。激光加工中产生的等离子体，可以实时反映激光与材料相互作用的过程。因此，为了促进激光加工过程实时监测技术的发展，本文采用铝合金标准样品研究了光纤激光诱导等离子体（Laser Induced Plasma，简称LIP）的物理特性参数和光斑重叠率对铝合金光谱强度的影响。研究的主要内容包括：

（1）研究了高频脉冲LIP的物理特性参数。采用Boltzmann平面法和Lorentz拟合光谱曲线，获得等离子体平均温度和平均电子数密度。通过调节激光功率表明，提高激光脉冲能量可以提高等离子体平均温度并降低平均电子数密度。

（2）高频脉冲激光的光斑重叠率对铝合金光谱强度的影响。通过调节激光功率，验证了光谱强度随着激光功率的增加而增强，且激光单脉冲能量的增加没有造成明显的等离子体屏蔽效应。提出了单点脉冲数（Single Point Pulse Number，简称SPPN）表征光斑重叠率，建立了光斑重叠率对光谱强度影响的物理模型，对光斑重叠率与光谱强度之间的函数关系进行了修正和再拟合，验证了物理模型的有效性，拟合度R^2可达到0.98以上。

关键词： 激光诱导等离子体；光纤激光器；物理特性；等离子体屏蔽效应；光斑重叠率

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Physical properties of aluminum alloy plasma induced by nanosecond pulse fiber laser

Yuzhi Qin, Zhiying Xu, Ning Zhang Jiaming Li*, Qiongxiong Ma, Liang Guo, Qingmao Zhang*
Guangdong Provincial Key Laboratory of Nanophotonic Functional Materials and Devices, School of Information and Optoelectronic Science and Engineering, South China Normal University
State Key Laboratory of Optical Information Physics and Technology, South China Normal University

*Corresponding author: jmli@m.scnu.edu.cn; zhangqm@scnu.edu.cn

Aluminum alloys has the characteristics of high strength density ratio, low thermal expansion coefficient, good electrical and thermal conductivity, low cost and so on, and is widely used in aerospace, construction, transportation, and all kinds of daily life products in industrial production and manufacturing. With the upgrading of China's manufacturing industry, the level of science and technology and the continuous development of industrial economy, the performance of aluminum alloys constantly put forward higher requirements. General aluminum alloy has low hardness and poor wear resistance, which is difficult to meet the technical requirements of increasingly complex working environment. The properties of aluminum alloys can be significantly improved by changing the structure and surface of the material by laser machining. Laser processing is very fast, so it is very difficult to monitor and characterize the laser processing in real time. The plasma generated in laser processing can reflect the interaction between laser and material in real time. Therefore, in order to promote the development of real-time monitoring technology for laser processing, the effects of physical characteristics of fiber laser-induced plasma (LIP) and spot overlap rate on the spectral intensity of aluminum alloy were studied by using the aluminum alloy standard sample. The main contents of the research include:

(1) The physical property parameters of high-frequency pulsed LIP were studied. Using the Boltzmann plane method and Lorentz to fit the spectral curve, the average plasma temperature and the average electron number density were obtained. By adjusting the laser power, it is shown that increasing the laser pulse energy can increase the average plasma temperature and decrease the average electron number density.

(2) Effect of high frequency pulsed laser spot overlap on spectral intensity of aluminum alloys. By adjusting the laser power, it is verified that the spectral intensity increases with the increase of laser power, and the increase of laser single pulse energy does not cause obvious plasma shielding effect. A Single Point Pulse Number (SPPN) was proposed to characterize the spot overlap rate, a physical model of the effect of the spot overlap rate on the spectral intensity was established, and the functional relationship between the spot overlap rate and the spectral intensity was revised and reconstructed. The validity of the physical model was verified, and the fitting degree R^2 can reach more than 0.98.

Keywords: Laser-Induced Plasma, fiber laser, physical property, plasma shielding effect, spot overlap rate