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基于分光调制的碳化硅陶瓷耦合激光刻线特征研究

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摘要：碳化硅陶瓷具有耐高温、耐磨损、抗空间粒子辐射等优异的热力学、物理力学、光学等性能，是代表性的空天高性能先进材料，也是典型的难切削材料。基于光束调制的难切削材料激光加工具有良好的工艺效果，是热点研究方向之一。本文采用经调制的多光束耦合激光刻槽加工碳化硅陶瓷，分析了刻槽特征尺寸、微观形貌以及元素分布随激光功率的变化规律，讨论了耦合激光的加工特性，阐明了材料去除机制和微槽成型表面的特点。研究表明，SiC 陶瓷刻槽加工时，在三种分光方案下，刻蚀线槽的深度、宽度总体上随激光功率的增加而增多，随激光功率的增加，槽深增加的速率变缓；功率从 1W 到 6W 的变化过程中，对应的槽深在 1 微米到 7 微米之间，槽宽在 40 微米到 70 微米之间；低功率加工时，13 束耦合分光方案对应的加工槽深大于 9 束、7 束分光方案加工的槽深，几种分光方案加工的槽宽尺寸相当；在一定的功率范围（3-4W）内，相同功率下 13 束分光方案加工的微槽槽深大于无分光方案，且在试验功率范围内 13 束分光方案加工槽宽均小于无分光片方案加工微槽宽度，故 13 束分光方案更易于产生较小槽宽、较大槽深的加工效果，适于小功率范围内的高能量密度激光微抛光；SiC 陶瓷刻线加工微槽特征比较规整，无明显的重铸层；本研究讨论了碳化硅陶瓷在四类耦合加工域作用下的微槽成型机制，拓展了难切削材料的激光加工工艺类型，为光束耦合激光去除材料提供了关键机理分析和工艺支撑。

关键词：分光方案；多光束耦合；碳化硅陶瓷；激光加工特性；刻槽微观形貌

Features of Laser Engraved Lines of Silicon Carbide Ceramics by Coupling Based on Spectral Modulation

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Abstracts: Silicon carbide ceramics have excellent physical mechanics, thermodynamics, optics and other properties such as high temperature resistance, wear resistance, fatigue resistance, and space particle radiation resistance. Laser processing of difficult-to-cut materials based on beam modulation has good process effects and is one of the hot research directions. In this paper, a modulated multi-beam coupled laser groove is used to process silicon carbide ceramics. The variations of the groove feature size, microscopic morphology and element distribution with laser power were analyzed, the processing characteristics of the coupled laser were discussed, and the material removal mechanism and features of the micro-grooved surface were elucidated. The research shows that the depth and width of the etched grooves generally increase with the increase of laser power when SiC ceramics were grooved under the three spectroscopic schemes. With the increase of laser power, the rate of increase of groove depth becomes slower. In the process of laser power changing from 1W to 6W, the corresponding groove depth is between 1 μm and 7 μm, and the groove width is between 40 μm and 70 μm. During low-power processing, the corresponding processed groove depth of the 13-beam coupling splitting scheme is greater than that of 7-beam coupling splitting scheme and 9-beam coupling splitting scheme. The groove widths processed by several beam splitting schemes are similar in size. Within a certain power range (3-4W), the depth of the micro grooves processed by the 13-beam splitting scheme at the same power is greater than that of no splitting. In addition, within the test power range, the processing slot width of the 13-beam splitting scheme is smaller than the micro-slot width of the scheme without beam splitter, so the 13-beam splitting scheme is more likely to produce the processing effect of smaller groove width and larger groove depth, which is suitable for small laser micro-polishing with high energy density in the power range. The micro-grooves of SiC ceramics with relatively regular features and no obvious recast layer were processed by coupling laser line processing operations. This study discusses the micro-groove forming mechanism of silicon carbide ceramics under the action of four types of coupled processing domains. The laser processing technology types of difficult-to-cut materials are expanded, and key mechanism analysis and process support are provided for beam-coupled laser removal of materials.

Keywords: Spectral Modulation; Multi-beam coupling; Silicon carbide ceramics; Laser processing properties; Groove micro-morphology

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