Cooling technology applied in optical elements of high power laser

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Abstract:At present, many researchers pay more attention to the thermal-effect of the high energy laser at home and abroad. A few technologies have been demonstrated, such as the water-cooling, the thermoelectric cooler, the phase-change cooling and so on. All of the technologies are induced to minimize the thermal deformation and damage of resonator mirrors and windows in high energy laser. The technologies are compared, the multilayer mirror is disscussed emphatically. The engineering experience verifies this method can meet the requirement of the high power laser system on very small mirror surface deformation. It is very important method for reducing heating effect of the high power laser.

Key words:Microchannel technology; Phase-change cooling; High power laser
CLC number: TN243 Document code: A Article ID:1007-2276(2007)01-0086-03

高功率激光器光学元件冷却技术的研究

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摘 要: 当前对由热效应引起的激光器及其光学元件变形和破坏问题的研究越来越受到国内外学者的重视。控制镜子温升的方法通常有改进水冷铜镜、采用半导体制冷、相变技术等。文中对这些方法进行了比较, 重点阐述了多层水冷这一新技术。工程实践结果证明, 该方法能有效地控制镜子温升, 将镜面变形控制在一个很小的范围内, 为解决阻碍高功率激光器发展的‘瓶颈’—热效应问题, 提供了有力的参考依据。

关键词: 微通道技术; 相变制冷; 高功率激光器

0 Introduction

Highpower laser system involves an optical train consisting of resonator mirrors and windows. Thermal stress and deformation may happen, when a mirror of the high power laser absorbs a part of the laser energy to make the mirror temperature risen.When the deformation is greater than a critical value, the beam quality and energy transmission to far-field will be affected. Seriously, this make output laser power decrease greatly and laser beam quality become worse for some high power lasers[1]. Therefore, the optical compone deformation

收稿日期: 2006-07-25; 修订日期: 2006-08-10
基金项目: 中科院二期创新资助项目(C04708Z)
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must be controlled to be very small. To do so, some cooling technologies are usually induced and used in high power laser systems.

1 Microchannel liquid-cooling technology

1.1 Background

Liquid -cooling has always been an effective method to minimize the deformation of resonator mirrors in high power laser devices. By designing the appropriate structure and utilizing fluid -filled cooling channels to absorb the heat, mirrors can be cooled and the deformation of the mirrors can be reduced. The heat exchange between the fluid and the mirrors' body depends on the properties of the fluid and the substrate of the mirrors, the flow state of the fluid, and the structure of the cooling channels. Generally, the flow states are divided into laminar flow, transition flow, and turbulent flow, where turbulent flow representing the highest heat transfer coefficient. The structure of the cooling channels influences the efficiency of the heat exchange, thus the better we design, the more we get efficiency.

1.2 Microchannel mirror technology

A microchannel mirror has been developed as a novel heat exchanger configuration[2-4]. It also has been developed to provide optimal heat exchanger distortion performance and reduce coolant flow induced vibration forces and the deformation of the mirrors. The microchannel mirror combines the simplified coolant distribution system of the channel crossflow design with the scalable high performance of the microchannel parallel flow design. A microchannel configuration depicted in Fig.1 with multiple

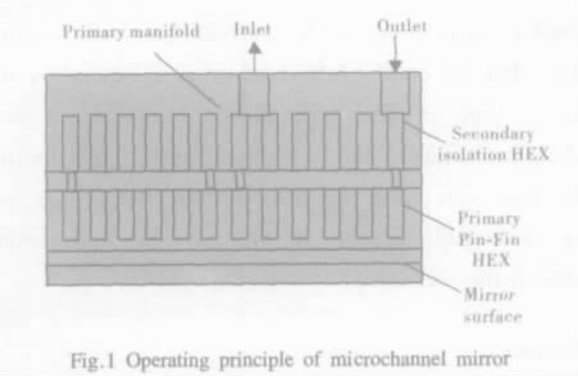

Fig.1 Operating principle of microchannel mirror

zones and redundant flow has been implemented but with a channel counterflow distribution system to minimize fluid interfacesand simplify supply manifolds.The microchannel mirror is comprised of a high performance microchannel impingement heat exchanger, a laminar channel secondary heat exchanger and a basal structure containing the primary coolant manifolds. The primary heat exchanger consists of a staggered pin arrangement with multiple inlets and outlets, the spacing of which determines pressure drop and coolant temperature rise. The microchannel configuration design features low flow velocity in the primary manifolds and secondary heat exchanger to minimize jitter. The channel secondary heat exchanger distributes coolant to the microchannel primary heat exchanger, and provides additional thermal isolation for the support structure. The microchannel parallel flow primary heat exchanger may be operated in either the low flow or high flow regime depending upon performance requirements. The result is a scalable, high performance heat exchanger consistent with the microchannel parallel design but with a less costly, simple counterflow coolant distribution system.

The exploded view in Fig.2 shows coolant enters a substrate primary plenum and flows through coolant feed-throunghs to the top of the substrate.The secondary

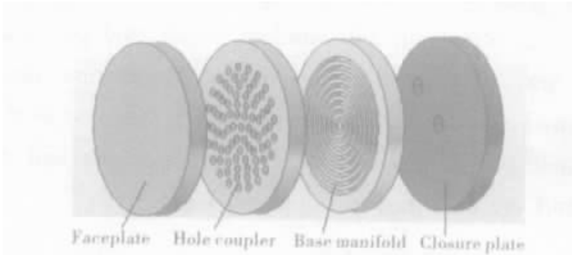

Fig.2 Exploded view of microchannel mirror configuration

heat exchanger con tains coolant distribution channels machined directly into the substrate and interface directly with the substrate feed -throughs. Alternating rows of inlet and exit channels arranged in a counterflow configuration to supply coolant to the multiport parallel flow heat exchanger and return exit coolant to the primary manifold. Coolant enters the microchannel heat exchanger through the hole coupler plate. The holes are aligned with their respective inlet distribution channels. Then the coolant flows across the zone to a coolant return port into an outlet distribution channel, and flows down the channel to the secondary outlet manifold through outlet interface tubes and into the primary exit plenum located in the substrate. As described above, a microchannel configuration with multiple zones and redundant flow has been implemented but with a channel counterflow distribution system to minimize fluid interfaces and simplify supply manifolds.

2 Phase-change cooling technology

For normal mirror, when the circular output beam passes through it, the mirror temperature will increase due to absorption process and then the mirror optical thickness will change correspondingly, causing wave front aberration and over-uneven intensity distribution, even mirror blasting[5]. But for the phase-change cooled mirror, with the existence of phase-change materials,the temperature can be approximately kept close to phase-change point. The phase-change materials start melting and absorbing quantity of heat from mirror body as soon as mirror temperature becomes higher than phase-change point. Before the phase-change materials completely melt, the window temperature is always kept. After output process, the melted phase-change materials emit quantity of heat through thermally conductive core, fix screw nut and window facing, and get ready for next time as well as mirror temperature drops down. So the phase-change material is the key to this technology.The phase-change cooling structure and the mirrors are described in Fig.3 and Fig.4.

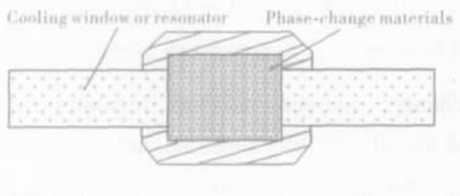

Fig.3 Exploded view of the structure of phase- change cooling mirror

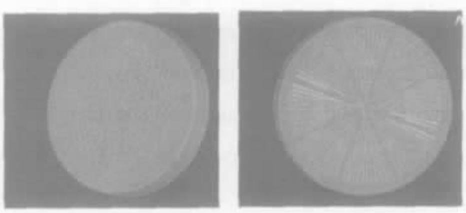
Fig.4 Out-shape of phase-change cooling mirrors

3 Analysis on the two cooling technologies

Compared with liquid-cooling technology, the microchannel mirror technology will change the structure and its strength, but the pressure which is brought by the liquid can not be removed absolutely. So when the thermal stress and deformation of the mirror must be special minuteness, the technology will be helpless.

The phase-change cooling technology also has an insufficiency: the phase-change materials need some time to change phase again, after they have worked for a period of time. So we try to integrate the phase-change technology into the multi-layer mirror technology. And the Fig.5 shows the operating principle of the integrated multi-layer mirror technology.

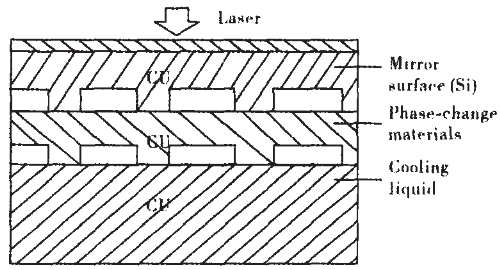

Fig.5 Operating principle of the integrated multi-layer mirror

4 Conclusion

The micro channel liquid-cooling technology can meet the requirement of the high power laser system on very small mirror surface deformation, whereas the pressure which is brought by the liquid can not be removed absolutely. The phase-change cooling technology all can avoid the distortion and vibration of the resonator mirror produced in conventional water-cooling system, but the cooling effect of them is limited by the working time of the high power laser. As a new cooling technology, the integrated multi-layer mirror technology can solve these problems, but it has not been developed enough, so we have to make more efforts to the technology in the future.

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滤波后对应 Allan 标准差双对数曲线。表 1 为滤波前后各项噪声系数的对比。

表 1 滤波前后噪声误差系数

Tab.1 Noise error coefficient before and after filtering

Filtering algorithms	Q/μrad	N/(°·$h^{-1/2}$)	B/(°·h^{-1})	K/(°·$h^{-3/2}$)	R/(°·h^{-2})
Original signal	20.090 4	0.011 6	0.053 2	0.008 3	1.606 6e-4
Median filtering	0.853 8	0.009 9	0.052 1	0.008 2	1.531 2e-4
Wavelet soft threshold filtering	0.296 0	0.002 4	0.050 0	0.006 1	1.053 0e-4
Wavelet median filtering	0.091 5	7.080 4e-4	0.016 1	3.867 5e-4	3.097 0e-6

4 结 论

由图 2(b)~(d)和表 1 可以看出, 激光陀螺零漂测试数据经三种滤波算法滤波后各项噪声系数均有所减小, 但文中所设计的小波中值滤波算法效果最好, 经过滤波后, 量化噪声和角度随机游走分别减小为原来的 0.46%和 6.1%, 零偏不稳定性下降至滤波前的 30.26%, 速率随机游走和速率斜坡也分别下降为原来的 4.66%和 1.93%。

由此可见, 通过设计小波中值滤波器, 将小波和中值滤波有效地结合起来, 滤波效果非常明显。经小波中值滤波算法滤波后, 激光陀螺信号的绝大部分随机噪声已经得到抑制, 随机误差已减小至很小的程度, 其滤波效果较为理想, 激光陀螺的测量精度也大大提高。

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