

Ultra-Low Surface Roughness Polishing and Metrology 蔡斌或 Bence Cai - 华南区客户经理



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2023/09/07



Edmund Optics Company

全球化的工程与制造

- 广为人知的产品手册
- 作为定制晶圆厂和工程解决方案的提供商,拥有超过20年的
 经验
- 每年内部制造超过200万个光 学器件
- 亚利桑那大学的特别项目





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亚埃表面对哪些市场有利?

需要光学和能量效率的应用

- ☆ 紫外线范围及以下
- ◆ 超低散射
- ✤ 高功率激光系统
- ↔ 计量系统



Images from Ultrafast Innovations GmbH

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亚埃表面对哪些市场有利?

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- ✤ 高功率激光系统

医学的

- * 眼科手术
- ✤ 成像系统



❖ 导航系统



Image from FoxTrotAlpha

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超低表面粗糙度







抛光基础

传统的减法抛光从表面形成开始

- 固定磨料 (Blanchard 等)
- 松散磨料
- 逐渐变细的砂砾
- SSD是材料机械移除的自然结果







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亚表面损伤层

原子级键非常强

- 抛光颗粒具有不规则形状
- 颗粒将材料从基材上剥离

一些基材仍与剪切材料粘合

- 玻璃碎片的不规则表面
- 玻璃上的颗粒压力导致破裂

剪切面下方的材料移除会产生表面空隙 ■ 一些可见,一些潜在(SSD)









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SPIE Paper 11175-05, 2019 doi: <u>10.1117/12.2536689</u>

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"疯狂就是一遍又一遍地做同样的事情,期望得到不同的结果"

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化学机械抛光(CMP)

- 氧化铈、氧化铝、氧化锆和二氧化硅是常见的抛 光剂
- **水通**过打破Si-O化学键软化玻璃:
 - ∘ SiO₂ + 2(H₂O) → Si(OH)₄
 - 。 Si-OH 分子形成 (Si(OH)₄)

现实情况下:在拜尔贝层以下的侵蚀性清除;SSD

<u> 理想情况下:材料去除发生在改性 Si(OH)4层</u> 从表面去除时



5102 Bulk Substrate SiO_ **Bielby Layer** OH Ce OH OH Ce OH OH Ce ON OH

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H2O在Sio2中的扩散

- 扩散系数估计约10 15 cm2 / sec * (非常 低的价值)
- 扩散深度测量值0.5 nm≤d≥12.0nm **
- H2O在Si O2中的溶解度随静水压力和压 应力的增加呈指数增加
- 扩散系数呈指数递减 (Lee Cook paper)

*"Diffusion of Water in SiO2 at Low Temperatures", Lanford, Doremus, et al, "Advances in Materials" Characterization II", 1985, p203

SPIE Paper 11175-05, 2019 doi: <u>10.1117/12.2536689</u>

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抛光科学





** "Effect of Stress on Water Diffusion in Silica Glass", Nogami & Tomozawa, J of Am Cer Society, 67, 1984, *p151*

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浸没式抛光*

- **新**鲜浆液的恒定输入
- 保持磨盘表面处于水化状态
- 恒定的温度
- 表面张力对空气中的污染物形成屏障
- 拜尔贝层的不间断形成
- 更高的粒子混合概率

对于制作出亚埃级表面至关重要









超级抛光工艺对比

标准流程-WLI

- ■颗粒穿过拜尔贝层并进入基底(0.5µm ≤ Ø ≥ 1.5µm)
- ■擦痕、沟槽和表面结构的证据
- 23 Å P-V, 3 Å Ra

EOT エ艺 – WLI

- **■反复去除拜**尔贝层
- ■证明为随机表面结构,没有划痕或沟槽 ■ 3 Å P-V, 0.25 Å Ra











超级抛光工艺对比

标准超级抛光-AFM

- ■非常好的表面- 1.55 Å平均粗糙度
- 29.6 Å P-V
- 表面微结构依然明显

EOT 超级抛光 – AFM

- ■优异的表面-1.07 Å平均粗糙度
- 3.71 Å P-V
- ■表面已被清理干净











 $RMS = \sqrt{\int_{f_1}^{f_2} PSD(f)df}$

需要完全定义空间频率带 宽(SFB)

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轮廓



0.02 – 13 [mm⁻¹]

1 – 1800 [mm⁻¹]

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30 – 50,000 [mm⁻¹]

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标定表面特征







中空间频率



高空间频率





仪器功能

Graph: L. Deck, C. Evens, "High performance Fizeau and scanning white-light interferometers for mid-spatial frequency optical testing of free-form optics" SPIE (2004)







数据相关性

WLI 图



Spatial Frequency [mm⁻¹]





	P-V (Å)	RMS (Å)	Ra (Å)				
Average	183.416	7.423	5.701				
Range	2089.920	18.240	11.190				
Std Dev	186.88391	2.90696	1.81687				
		pe X Map Image: Constraint of the second	Surface Profile Image: Surface Profile				

Fused Silica Incomina Material

Fused Silica Final Results 2 Hr Polishing Time

	<i>P-V (</i> Å)	RMS (Å)	Ra (Å)
Average	7.862	0.448	0.333
Range	1.131	0.034	0.101
Std Dev	0.97763	0.02217	0.02024
		Be X Map +0.00040 +0.00020 -0.00020 -0.00020 -0.00020 -0.00020 -0.00020 -0.00040 PV rms	Surface Profile

熔融石英表面

熔融石英平面抛光

- 2小时抛光后达到亚埃级
- 没有可测量的SSD



N-BK7 表面

N-BK7 Incoming Material

	P-V(Å)	<i>P-V (Å) RMS (Å)</i>		
Average	256.370	11.397	6.004	
Range	538.988	17.017	1.989	
Std Dev	205.748	0.671		
		ee X Map +0.00200 +0.00075 ⊕ -0.00050 ⊕ -0.00175 -0.00300 0 PV Tms	Surface Profile Junta de P	

N-BK7 Final Results 2 Hr Polishing Time

	<i>P-V</i> (Å)	RMS (Å)		Ra (Å)
Average	15.887	1.095		0.839
Range	ge 3.392 0.065		0.047	
Std Dev	1.70506	0.03253		0.02354
	S 2490 Slop	e X Map	2 2990 +2.0 → +1.0	Surface Profile

N-BK7 平面抛光

- 2小时抛光后达到亚埃级
- 与熔融石英窗口片同时做表面处
 理
- **粗糙度**Ra 值大概比熔融石英高 出25%
- N-BK7 包含了 SiO₂, B₂O₃,
 Na₂O, Al₂O₃, 等其他元素





- EO 产品编号 #68527
- 光学级硅平片
- 25.0mm Ø, 3.0mm CT
- 持续抛光
- 浸没式工艺
- 0.368 Å Ra
- 5.871 Å P-V

New View, 20X Mirau, 1X Zoom, BPF, FFT Fixed, 9 - 250 mm⁻¹, 10X Average, Sys Err Removed

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超级抛光-硅

	1	ncoming Material	1
	P-V (Å)	RMS(Å)	Ra (Å)
Average	802.180	38.217	14.581
Range	657.097	58.222	32.398
Std Dev	229.81659	21.45135	13.15213
	657.097 58.222 229.81659 21.45135		Surface Profile Image: Control of the state

Final Results 2 Hr Polishing Time

	P-V(Å)	RMS (Å)	Ra (Å)
Average	5.871	0.483	0.368
Range	4.435	0.093	0.074
Std Dev	1.22176	0.02710	0.02125
	Zygo slop	e X Map ↓	Surface Profile Image: Constraint of the second secon

超级抛光 - 氟化钙

	Incoming Material					
	<i>P-V(</i> Å)	RMS (Å)	Ra (Å)			
AVERAGE	163.835	15.502	11.729			
RANGE	734.679	15.537	10.326			
STD DEV	227.9093	4.3495	3.1080			
	B Zygo Slope X	Map * 2990 * 60.0 + 35.0 + 10.0 * 50.0 + 10.0 • 0.000 PV 82.7 rms 18.6	Surface Profile			

Final Results 2 Hr Polishing Time

	P-V(Å)	RMS (Å	ĺ)	Ra (Å)		
Average	18.274	0.964	-	0.713		
Range	19.657	0.213)	0.121		
Std Dev	5.99559	0.0727	7	0.04265		
Slope		X Map	≥ Zugo € +4.0 +2.0 +2.0 -2.0 -4.0 0.000 PV 5.1 rms 0.9	Surface Profile A A 0.100 0.200 0.300 Distance (mm) 32 Å Ra 0.718 15 Å		

New View, 20X Mirau, 1X Zoom, BPF, FFT Fixed, 9 - 250 mm⁻¹, 10X Average, Sys Err Removed

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- EO 产品编号 #47683
- 真空紫外线等级CaF₂
- 25.0mm Ø, 3.0mm CT
- 持续抛光
- 浸没式工艺
- 0.713 Å Ra
- 18.274 Å P-V

B Zygo		Microscope	Stitching Application						
Obi : 20x Mirau	8 Zygo		Surface Map		a zygo		Process		
Zoom: 1.00 X		8 Zygo	3D Model	<u> </u>	Store	Undo Cl	ear A	uto Store:	On
Res : 0.55 µm	+62.0						ធ	indow Size	: 75
FOV : 0.35 x 0.26					8 Z490		Process St	ats	
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Analyze						Å	Å	Å	mm
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Save Data	A				3				
Calibrate					5				
Home Z					6				
Home XY			Same and the second		7				
Measure Controls					9				
Analyze Controls					10				
	-44.8				11				
					13				
	Ra 14.432 Å Remove	ed: Plane			14				
	rms 17 593 Å Size X	2 0.35 mm	TUDO Guerlan Controla		15 16				
Focus Controls		· 0-26			17				
	PV 106.803 A 5126 1		Phase Avgs: 10		18				
	Filter High Wavelen: 4.00931 µm RadCrv	v -2.54E+011 nm	Phase Avg Pause: Off		20				
Stitch Controls	Filter Low Wavelen: 112.26074 µm				21				
	Filter High Freq: 249.41935 1/mm		Subtract Sys Err: On		22				
Sequence Controls	Filter Low Freq: 8.90783 1/mm	Average X PSD	Sys EIT FILE: SysEIT_ZOA_IA.dat		23				
Surface Profile	Clip Data Height nm	Average Y PSD	Cours Sug Err Data		Range	0.000	0.000	0.000	0.00
			bave sys bil Data		Mean	106.805	17.593	14.432	-142290.61
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	Surface Profile								
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超抛前 CaF₂



Zygo		Microscope :	Stitching Application						4
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	Filter High Wavelen: 4.00931 µm RadCrv	2.95E+012 nm	Phase Avg Pause: Off		19				
Stitch Controls	Filter Low Wavelen: 112.26074 µm				20				
	Filter High Freg: 249.41935 1/mm		Subtract Sys Err: On		22				
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超抛后 CaF₂

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• 超抛技术高度依赖于研磨浆液化学

- 化学主要受玻璃类型和抛光化合物的 影响
- 在比较结果时,适当的计量工具非常 重要
- 通过工艺控制可以获得去除可测量 SSD的近乎完美的表面

■ 熔融石英、NBK-7、Si、CaF2均达到 亚埃水平

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