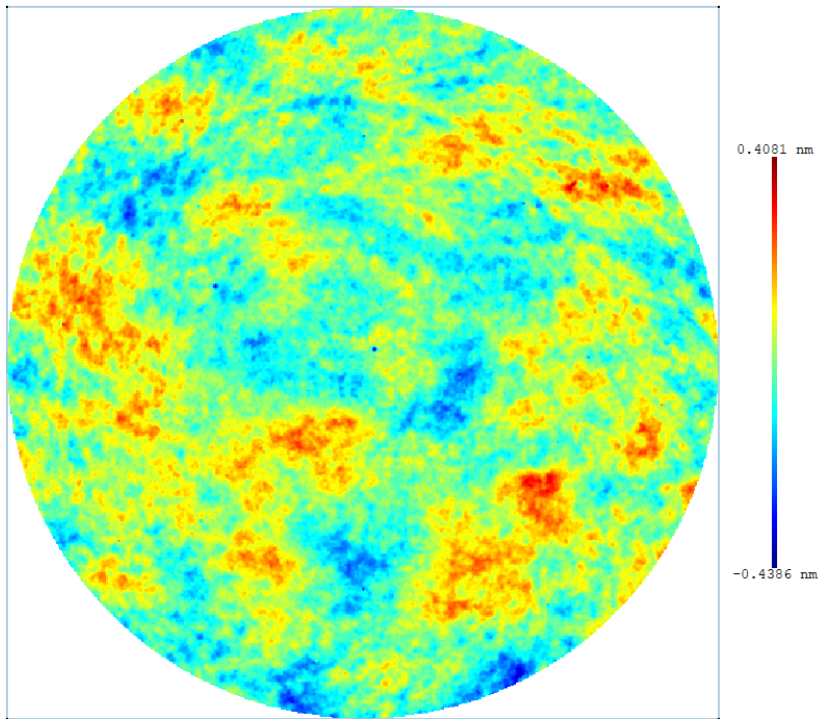
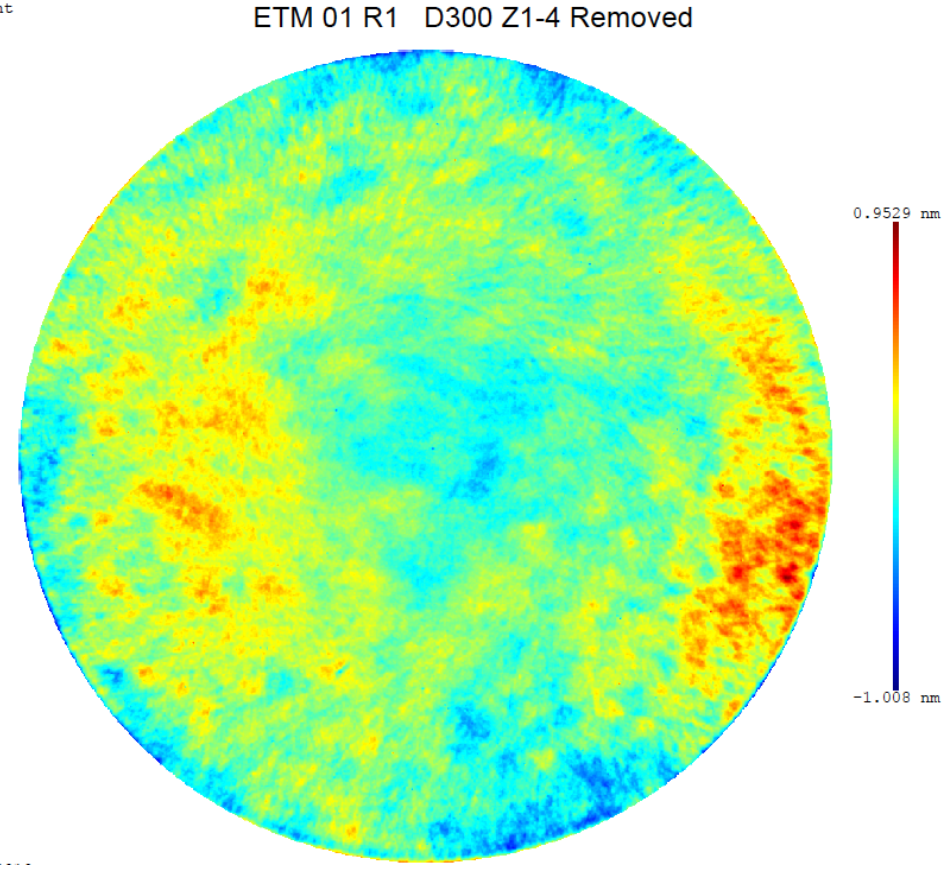
Advanced LIGO Core Optics expanding the imagination….

- Some things we have learned in Advanced LIGO have been surprising.
  - » 0.1nm rms figure error is achievable over large diameters
  - » Some fused silica can have high spatial frequency inhomogeneity
  - » Some fused silica isn't stable
  - » A q-tip can polish glass
  - » Drag-wiping can damage glass
  - » Low absorption AR coatings are more difficult to achieve than HR

Surface Figure: better than we thought possible

(Subcontractor L3 Tinsley)

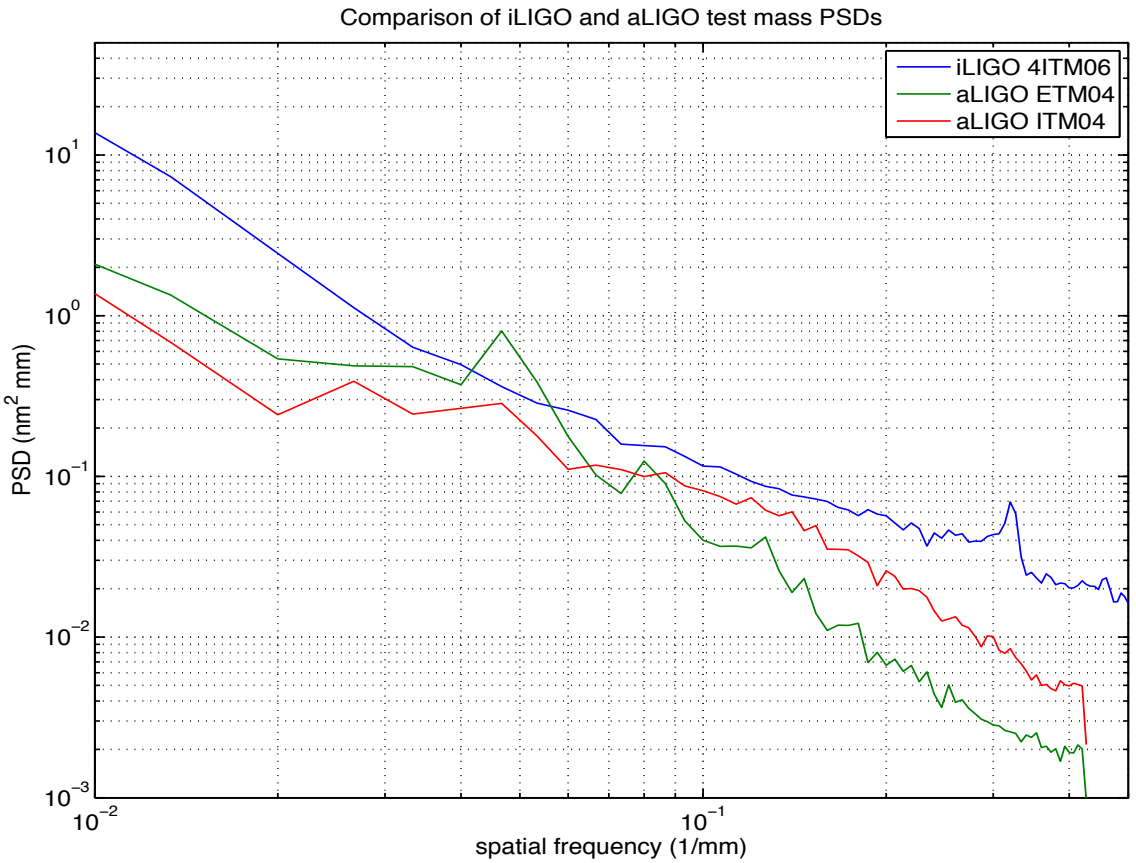




Φ 160 mm 0.0966 nm rms

Φ 300mm 0.17 nm rms

Compare Initial LIGO and Advanced LIGO PSD



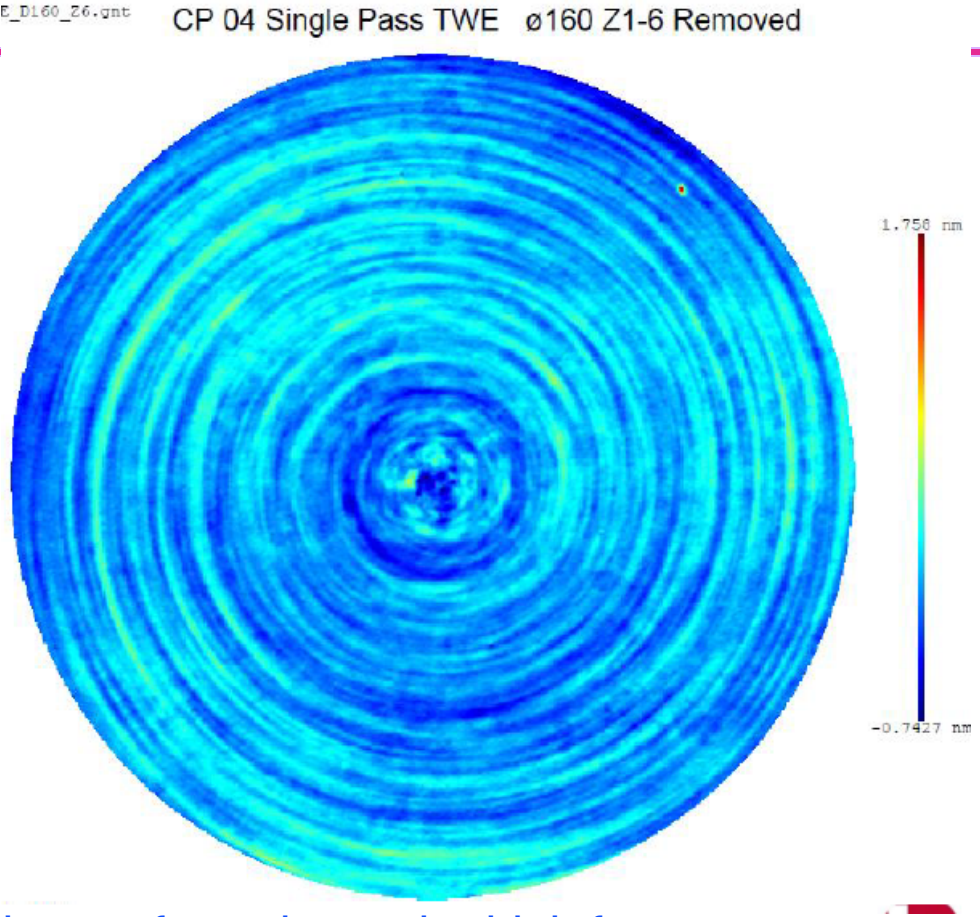
ETM04 diffractive loss = 4.7 ppm

ITM04 diffractive loss = 2 ppm

These are typical/ high for aLIGO TMs

Data analysis: Hiro Yamamoto

CP04 transmitted wavefront 0.16 nm rms (Image Zygo)



Neither surface shows the high frequency structure.

Heraeus 3001 ~2.4nm PV

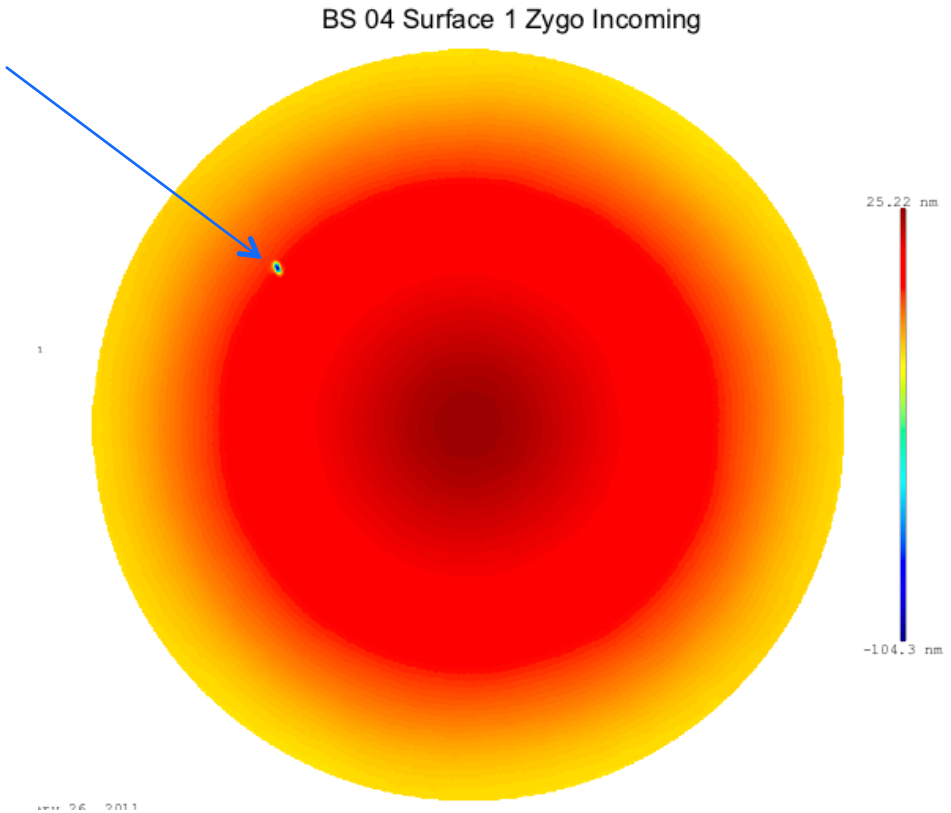
Fused Silica Figure Stability

Key Quantity tested - Approx. Anneal Temp (C°) - Sag Change (nm/150mm diameter)	Corning 7980	Heraeus		
		311	✪312	3001
LASTI TM	1 – 600 - 3			
*aLIGO FM Before & . After a high temp anneal at Corning	3 - 450/600 - 25-30 1 – 450 - 20			
*Mini FM			1 – 600 - NS#	
*aLIGO ETM 6 installed, 4 spares	2 – 600 - ±50	2 of 4 – 600 – NS#	6 - proposed	
*aLIGO ITM				2 – 600 - NS#
*aLIGO BS				1 – 600 - NS#
aLIGO R3	Sag tolerance is ± 400nm			
iLIGO ITM			12 – 450 - 18	
iLIGO BS		4 – 450 - 17		
iLIGO ETM	2 – 450 - 33			
✙iLIGO RM	4 – 450 - 14			
iLIGO FM	2 – 450 - 50			

*optic measured before/after anneal without coating. IBS coatings impart a compressive stress which has a more significant effect on high aspect optics.
†Measured over 150mm diameter
✪Proposed aLIGO ETM
#Not Significant compared with measurement error ~1-2nm
✙Interesting to note that the RMs were a different grade homogeneity than FM/ETM

Careful cleaning can leave a mark

(Image Zygo)



129 nm Peak to valley – Possibly caused by cleaning with a Q-tip. Cotton does not polish, but dust does.

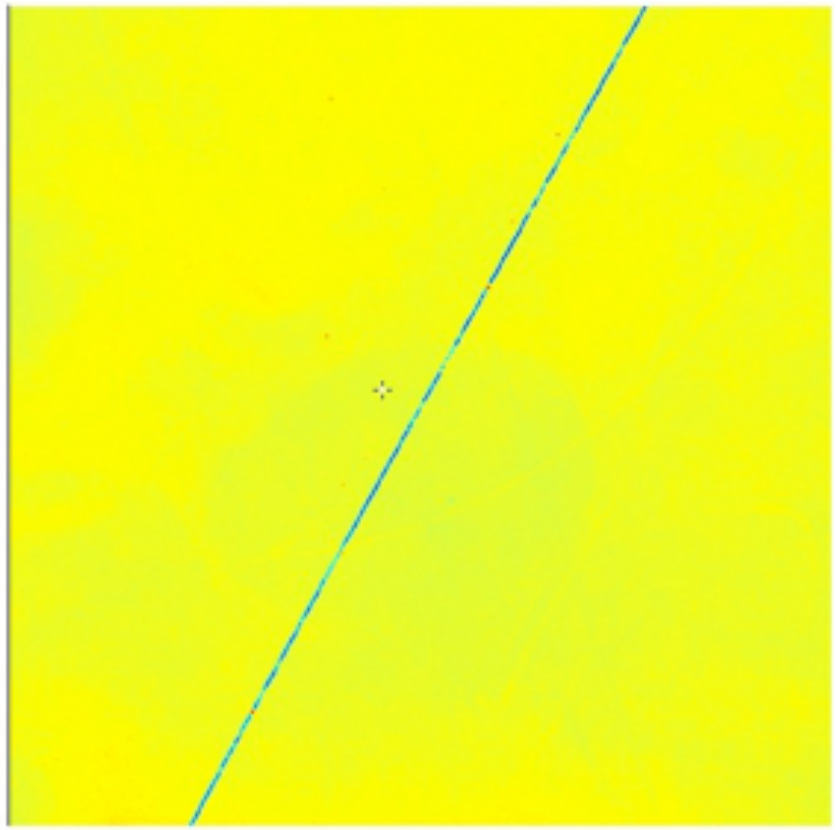
Two other optic show this to a lesser degree ~10nm PV, some in multiple spots.

This optic was repolished.

Wiping can leave sleeks

(Image L3 Tinsley)

```
units: x = mm
       y = mm
       z = nm
xspac: 0.0002778
yspac: 0.0002778
ngx  : 1020
ngy  : 1022
gxcen: 0
gycen: 0

z ptv: 22.84
z rms: 0.5911

x-apr: 0.28
y-apr: 0.2831

z min:-13.92
  @ (778, 1001)
z max: 0.921
  @ (594, 672)
z avg:-0.0009617

ndata: 1038360

ix   : 465
iy   : 546
xpos :-0.0126
ypos : 0.0096
r    : 0.0159
theta: 142.8291
zval : -0.267

color: jet
```

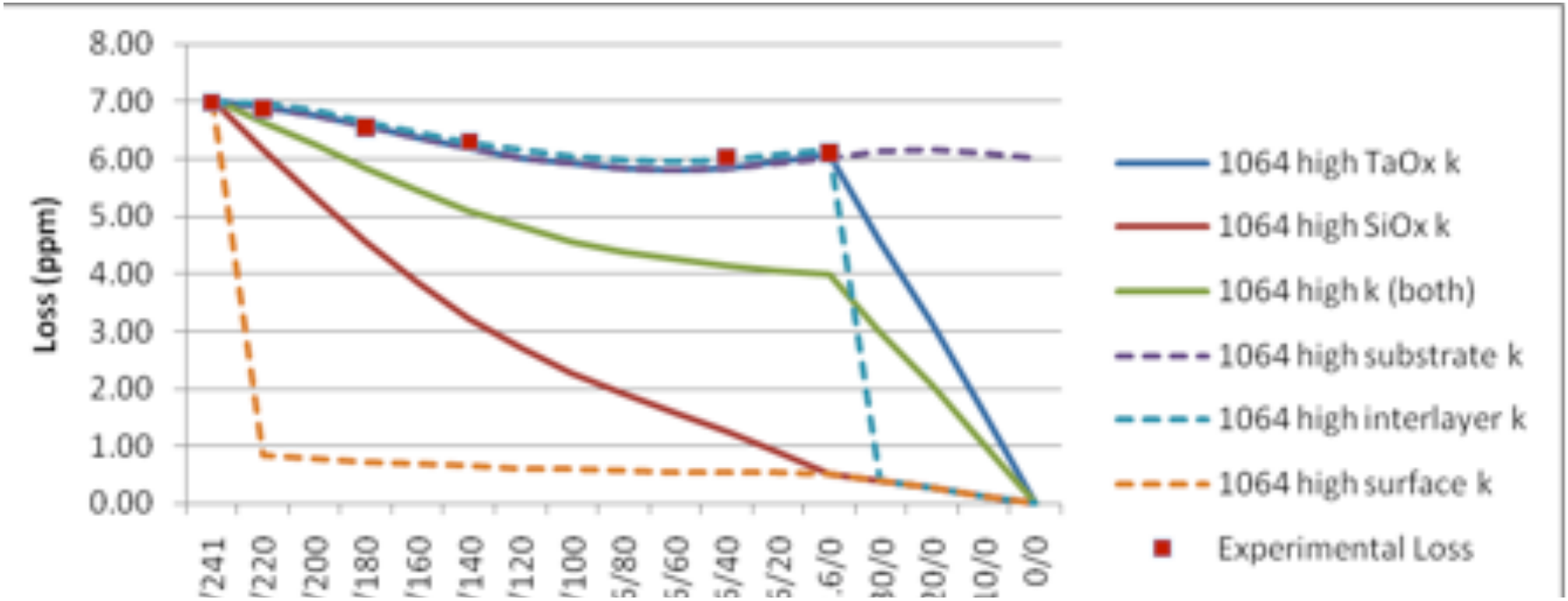


Sleeks can be caused by wiping; defect depends on the particulate being wiped.

Recommend using First Contact.

LIGO-E1000079

Exploring AR coating loss vs coating depth (Image CSIRO)



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Acknowledgements

Advanced LIGO Core Optics Team:

GariLynn Billingsley, Gregg Harry, Bill Kells, Patrick Murphy, Margot Phelps, Hiro Yamamoto, Liyuan Zhang

With significant help from: Dennis Coyne, Peter Fritschel and Eric Gustafson

Advanced LIGO Core Optics Vendors:

Glass: Heraeus Quartz America, Corning

Polishing: Coastline, Zygo (formerly ASML) under contract to L3 SSG Tinsley

Coating: CSIRO, LMA

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Follow our progress

https://nebula.ligo.caltech.edu/optics/

Some reports are “C” documents, limited to LSC viewing since they are provided as contractual documents.