## SURFACE TWIST CHARACTERIZATION AND COMPENSATION OF AN ELLIPTICALLY BENT HARD X-RAY MIRROR

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### CONTENT

- Bendable KB mirrors for APS upgrade
- X-ray optics metrology
- Mirror twist correction
- Conclusion



# BENDABLE KB MIRRORS FOR APS UPGRADE

### **APS Upgrade Project**

- New-generation light source (MBA lattice)
  - High degree of coherence
  - Small beam: nano-focusing
  - High flux density
- New beamlines
  - 9 new feature beamlines
  - 15 enhanced and improved beamlines
- State-of-the-art X-ray optics
  - Mirrors with sub-nanometer RMS height error
  - Lenses with sub micron thickness error
  - Nano focusing optics (KB mirrors, Zone plates, ...)
  - Adaptive optics (variable focal sizes, wavefront control and correction)





## **BENDABLE KB MIRRORS FOR APS UPGRADE**

### High-precision Bendable KB mirrors

- In-house bender design for elliptically bent hard X-ray mirrors
  - Compact laminar flexure bending mechanism
  - Two-moments bending



- High-quality mirror substrates with sub-nm figure errors
- A capacitive-sensor-array-based real-time mirror profiler





Deming Shu, et al., *AIP Conference Proceedings* **2054**, 060015 (2019). Jason Anton, et al., Proc. SPIE. **11100**, 111000B (2019). Deming Shu, et al., 34th ASPE Annual Meeting 2019, 111 (2019).



## **METROLOGY TOOLS: AT-WAVELENGTH**



Speckle tracking



- □ Phase contrast imaging
  - Phase
  - Dark-field
  - Tomography
- □ At-wavelength metrology
  - Lenses
  - Mirrors
  - Crystals
  - Windows
- X-ray wavefront sensing
  - Alignment
  - Beam quality
  - Adaptive optics







## **METROLOGY TOOLS: OPTICAL**

#### Long trace profiler (LTP)

1D dimensional slope and curvature metrology for mirror with a length up 1.5 m and the resolution of 50 nrad rms



### Optical interferometer

2D dimensional surface metrology for mirror

#### Fizeau interferometer



https://www.4dtechnology.com/products/fizeau-interferometers/accufiz-infrared-fizeau/



### **METROLOGY OF A BENDABLE MIRROR**

### Previous experimental test at 1-BM







200

300

200

રે<sup>250⊧</sup>

### **METROLOGY OF A BENDABLE MIRROR**

#### Fizeau interferometer

Use a Fizeau interferometer (AccuFiz) (100mm aperture) to characterize a prototype bendable mirror in the APS optical metrology lab







### SURFACE TWIST OF A BENDABLE MIRROR

#### Surface twist:

- Obvious surface twist
- Slightly bending dependent





### SURFACE TWIST OF A BENDABLE MIRROR

Twist angle: angle difference line1 and line2

- Twist angle: ~50 µrad
- Bending dependent twist: ~2 µrad





## SURFACE TWIST OF A BENDABLE MIRROR

Twist requirement (ray-tracing simulation)

 Twist angle needs to be small enough (<40 µrad) to minimize focal size broadening and peak intensity reduction (<5%).</li>



## **MIRROR TWIST CORRECTION**

How to compensate surface twist of the bending mirror?

#### Motorized correction

• Additional motor to push the bending arm



#### Manual correction by shimming

 Thin film underneath the mirror adapter on one side to adjust the mirror twist



#### More motor, more cost, less stable



## **MIRROR TWIST CORRECTION**

#### Manual shimming

• One piece of Ultralen film (4 µm thickness) on one side of the downstream end



## **MIRROR TWIST CORRECTION**

Before correction

- Twist angle: ~50µrad
- Bending dependent twist: ~2 µrad

After correction

- Twist angle: ~0.9 µrad
- Bending dependent twist: ~0.6 µrad



### CONCLUSION

#### **APS-U Bendable mirrors**

- Proven design to deliver high performance demonstrated by a prototype mirror.
- Measurable twist (50 µrad) exists but close to specification.

#### Twist measurements

- Optical metrology (Fizeau interferometer) provides adequate resolution and sensitivity to measure mirror twist.
- 2D metrology is needed to determine twist angle.

#### Twist correction

- Twist correction procedure based on shimming is simple and adequate.
- No need to add an additional motor.
- Twist angle can be easily corrected to a few µrad, which satisfy all the APS-U bendable mirror specification.
- After correction, surface twist is not sensitive to bending.

#### Further studies

• Twist correction by shimming is sensitive to the assembling process and shimming material, need to optimize and standardize the procedure.



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**APS upgrade project** 



