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Does membrane strain impact the TES transition surface?

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Abstract

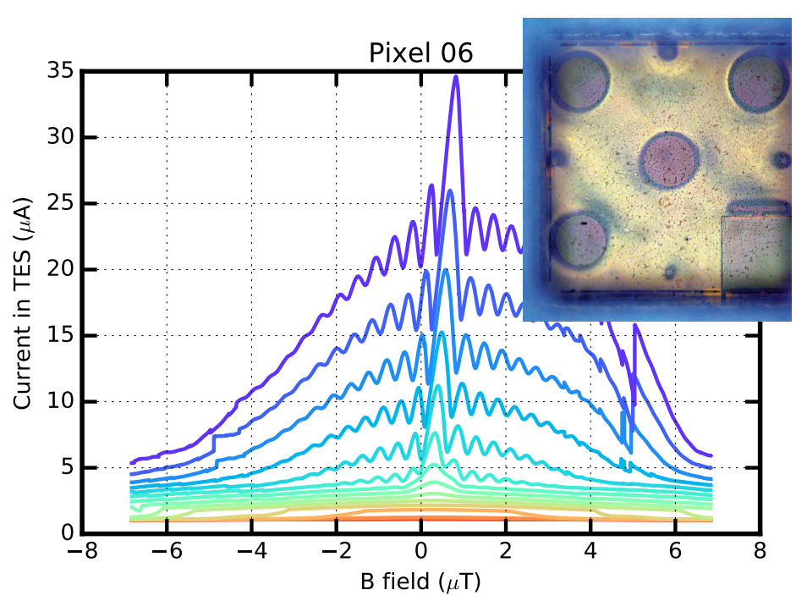
Recently, we have shown that uniaxial strain can shift the transition temperature of Mo by about 0.3K/(unit strain). Additionally, we have observed small strain induced changes in critical current. The implications of this finding on practical transition edge sensor devices depend on two questions: 1) How big are the strains encountered in real world devices, and 2) how does a strain induced change in Tc or Ic impact the resistive transition surface and thus device operation?

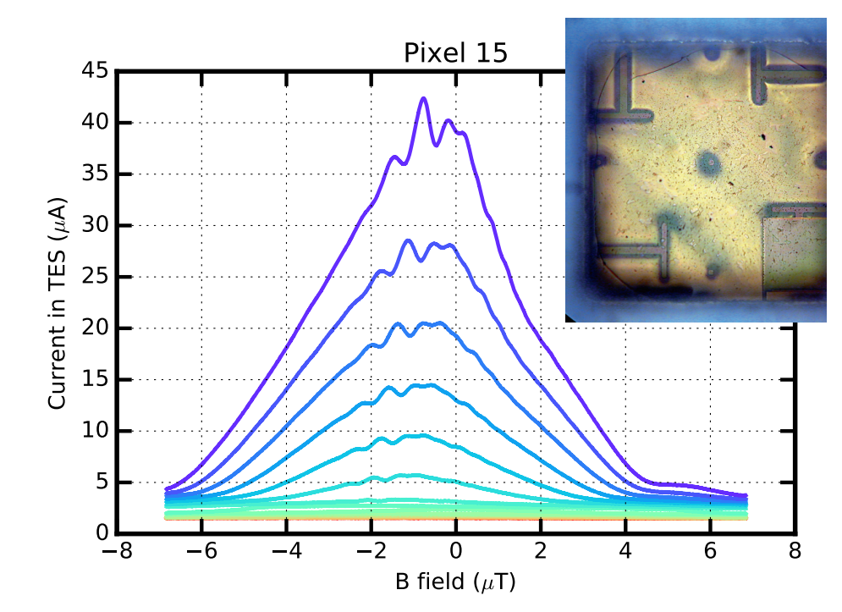
To answer the first question we use an optical technique to measure the curvature of TES fabricated on membranes and estimate the magnitude of the strains present in such devices.

The second question, however, is more difficult to address: the transition surface of typical devices shows a significant amount of structure commonly attributed to weak-leak effects. It is conceivable that local modulation of strain and Tc may lead to substantial qualitative changes in these important details of the transition surface. Since no detailed physical model has been proposed to predict these features, we attempt to tackle this problem experimentally. To this end, we are investigating methods to systematically modulate the strain field on a membrane.

Motivation

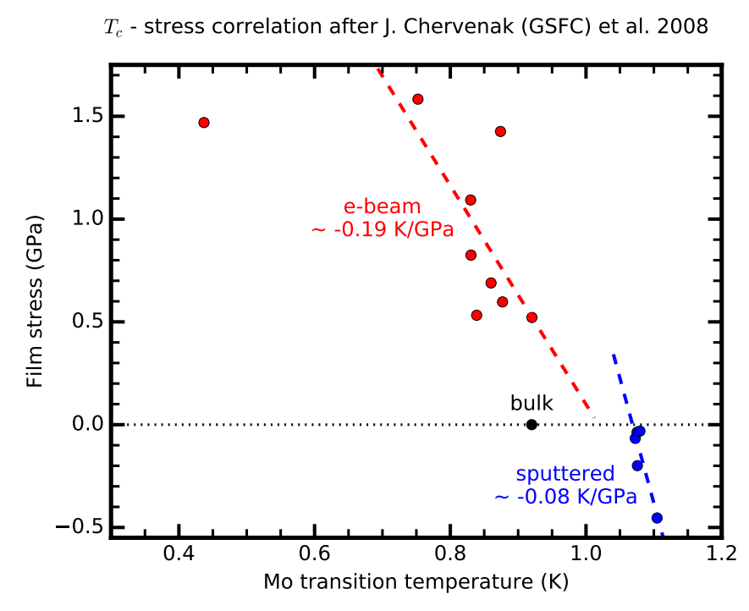
- Reproducible bilayer transition is a key ingredient to high-performance X-ray detectors
- Run-to-run variation of bilayer Tc remains challenging
  - Shifts up to 50mK attributed to stress effects [1]
- We need to better understand the underlying microscopic mechanisms
- Significant variation in transition surface (e.g. I(B)) seen between devices on the same wafer with identical TES geometry, but different absorber attachment or cracks in membrane



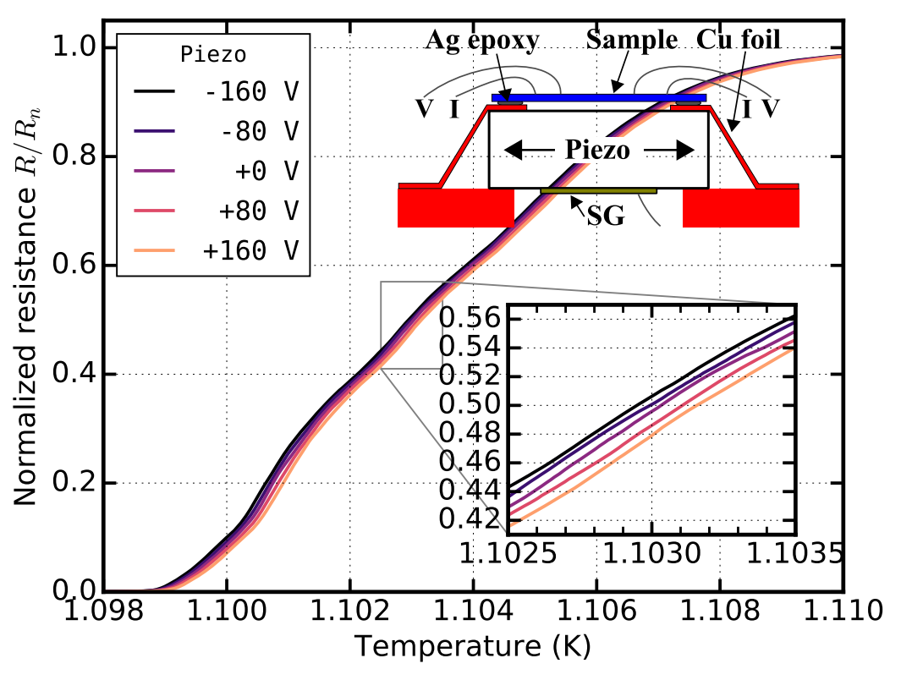


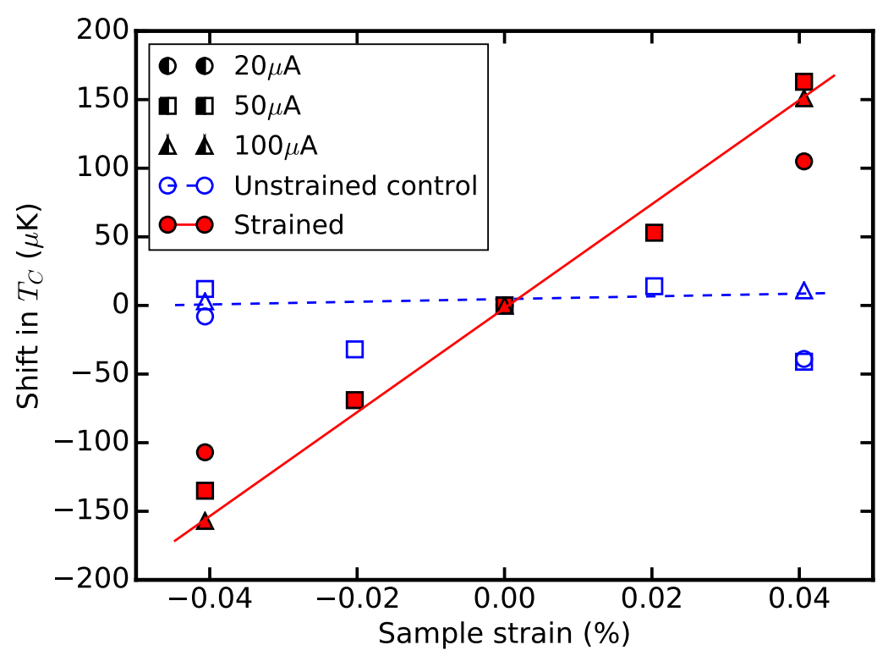
Background

- Bulk Mo Tc *pressure* dependence: **-14 mK/GPa**
- Apparent Tc on deposition stress:
  - E-beam evaporation onto heated substrates: in-plane tensile
  - Sputtered: atomic peening and produces high in-plane compressive stress
  - Tc increases with compressive stress
  - e.g. 0.98K at -0.2GPa to 1.2K at -1.2GPa [1,2], i.e. **-220mK/GPa**



- Direct measurement of strain dependence of Mo Tc ([3], presented at ASC 2016)





- Tensile stress increases Mo Tc at a rate of 0.38K/(unit strain), roughly ~ **1 mK/GPa**
  - Expect 100mK bilayer Tc to shift by ~30mK/(unit strain)
  - Considering transition width of ~1mK, it is plausible that strains on the order of 1E-3 could significantly alter current distributions
- Additional variations in strain fields may arise from:
  - added normal metal structures (banks, fingers)
  - membranes perforations (to reduce G)

Acknowledgements

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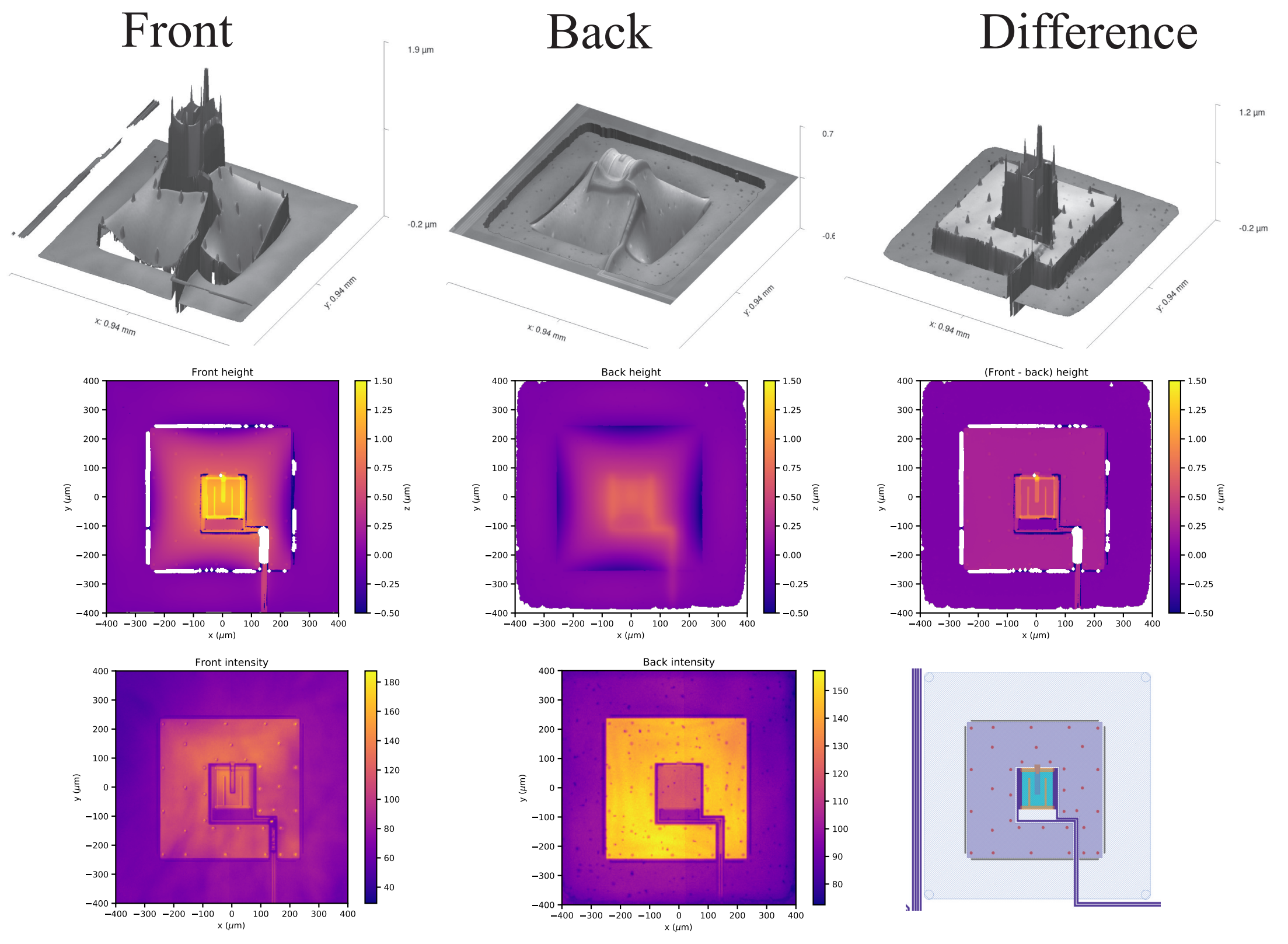
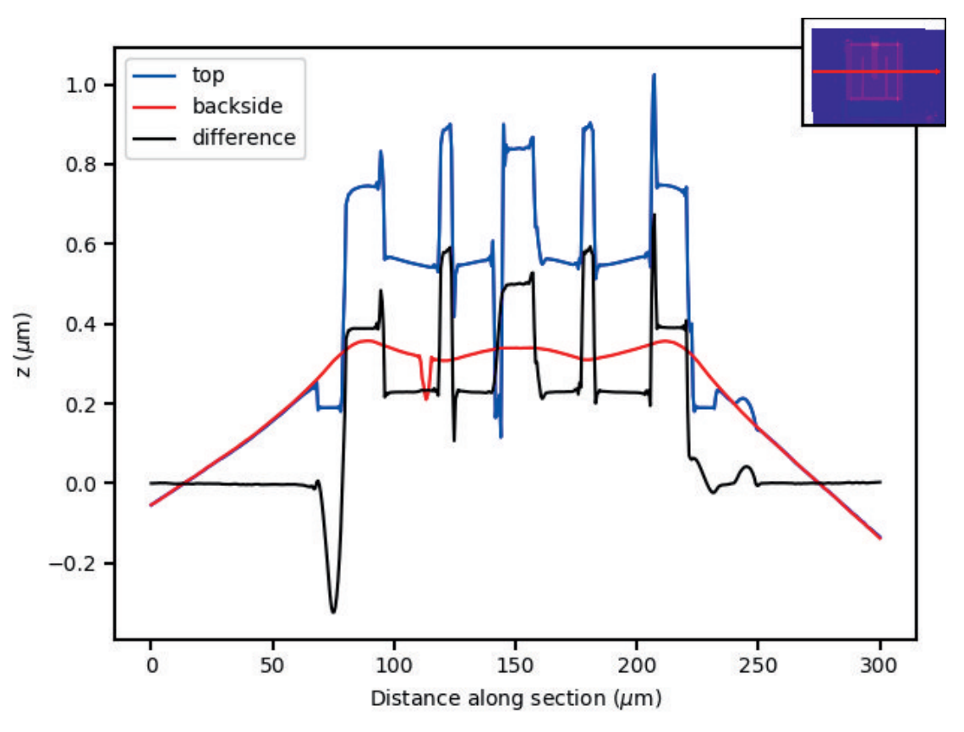
Optical profilometry to determine membrane surface profiles

- White light interferometer (Zygo NewView 6300) allows non-contact, non-destructive surface height mapping:
  - down to 0.5 µm lateral (depending on FOV)
  - ~1nm vertical resolution
- Can we determine membrane curvature by looking at the backside of the membranes?
- Membranes are transparent in visible light. Will front side metal structures create artifacts in the back-side/membrane height profile?
- Tested on MXW2[4] devices with a co-planar absorber design.

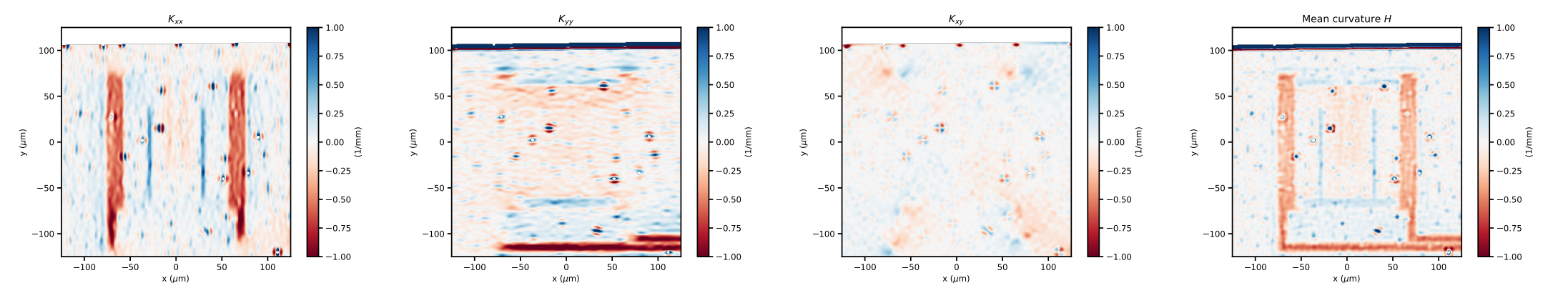


- Optical images show sharp contrast from front-side metal.
- Backside height maps are smooth.
- After alignment, front-backside profile subtraction yields flat profile in agreement with metal step heights.
- Backside height profile is an accurate representation of the membrane surface.



Extracting curvature

- Curvatures calculated from height map h(x,y) as second derivatives Kxx, Kyy and Kxy (twist). Also showing mean curvature H = 0.5*(Kxx + Kyy).



- Curvature is locally dominated by TES metal features:
  - Nb contacts (negative curvature, more compressive than underlying films): ~ -1/mm
  - Au fingers and banks (positive curvature, more tensile than underlying layers): ~ +1/mm
- Strain $\varepsilon = -\delta z * K$ can be calculated for a point δz away from the neutral plane.
- Location of neutral plane not known a priori, but roughly $\delta z \approx 0.5\mu m \rightarrow \varepsilon \approx 0.5E\text{-}3$
- A more detailed analysis can be undertaken if individual layer strains are known or can be determined.

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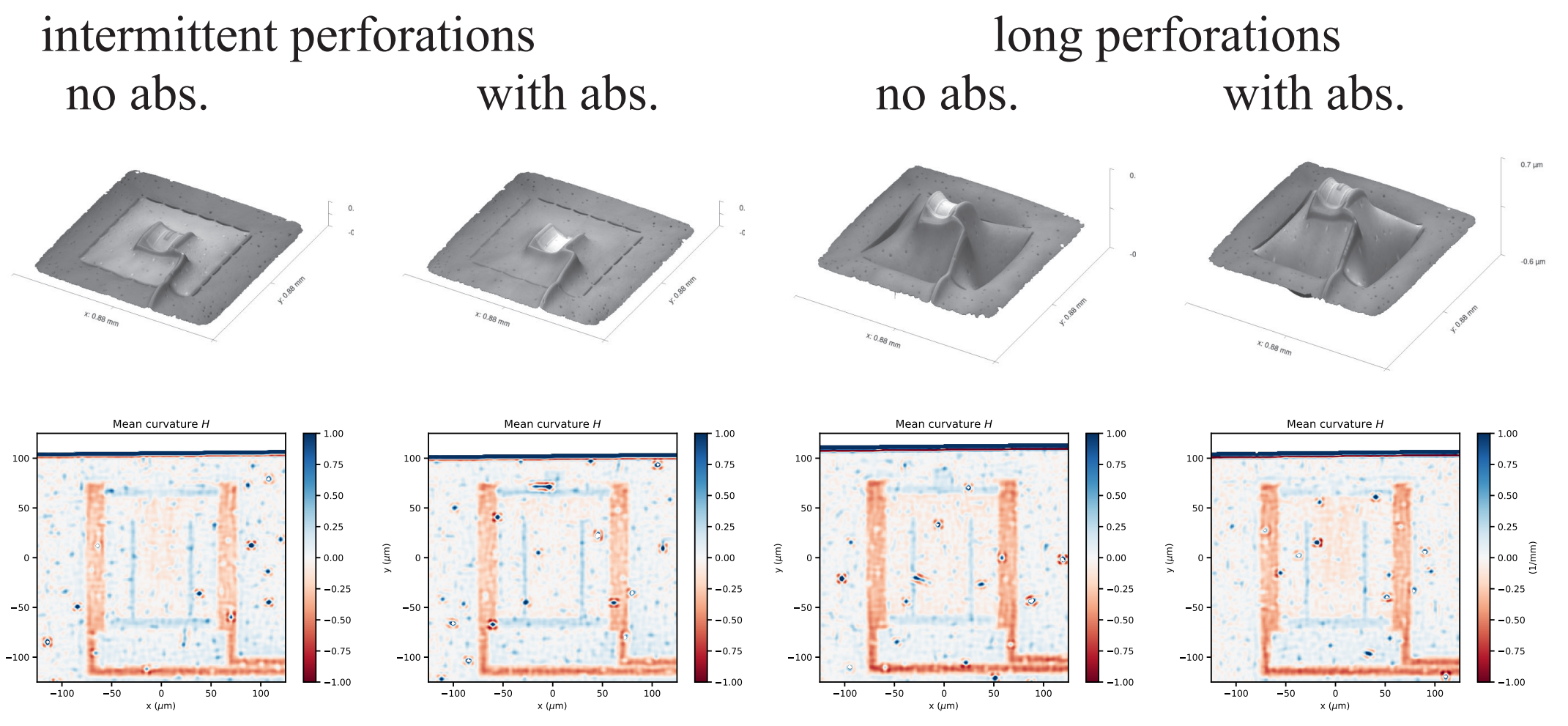
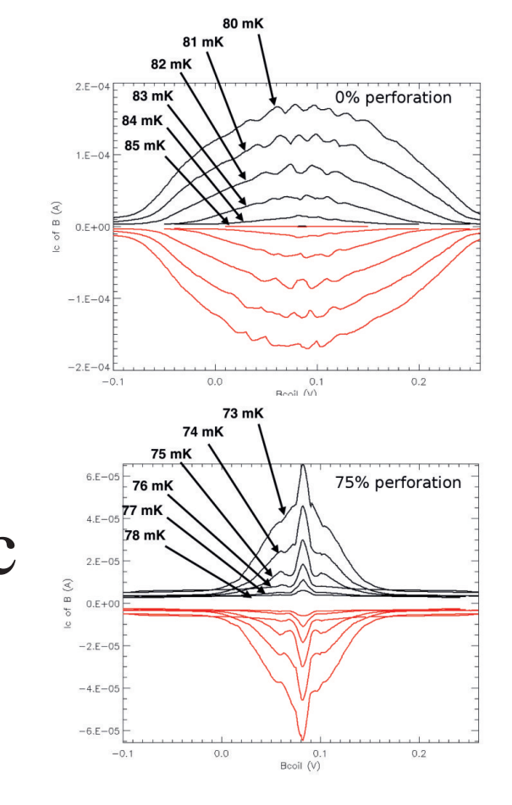
MXW2 membrane perforations

- Large area, thin absorber design for diffuse X-ray background measurements (50eV to 1keV) [2]
  - Targeting 1.5-2eV resolution: require high α, β
  - Mo (50 nm)/Au (240 nm)Banks/fingers: Au (360 nm)
  - (Co-planar) absorbers: 100 nm Au (evap.)/200 nm Au (electroplated)

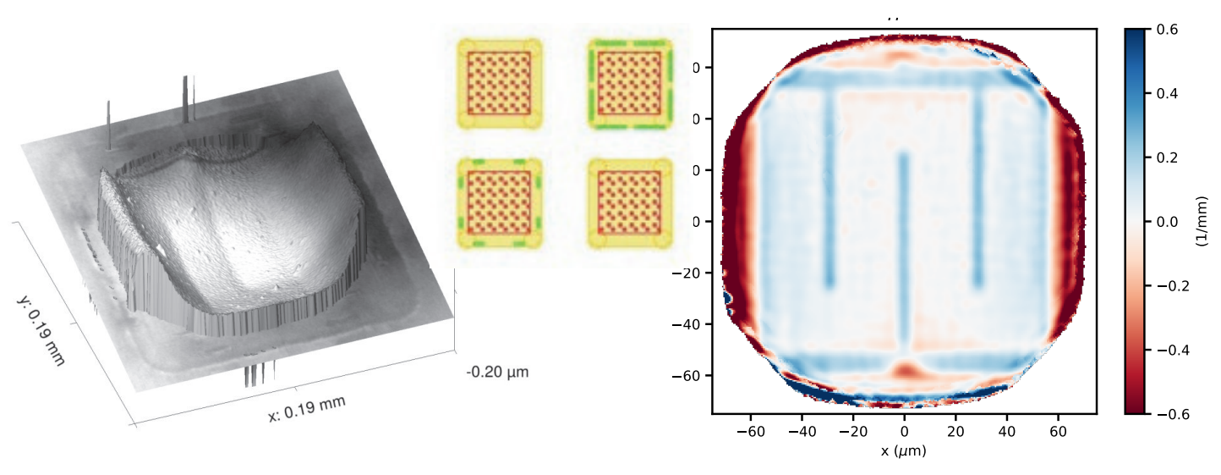


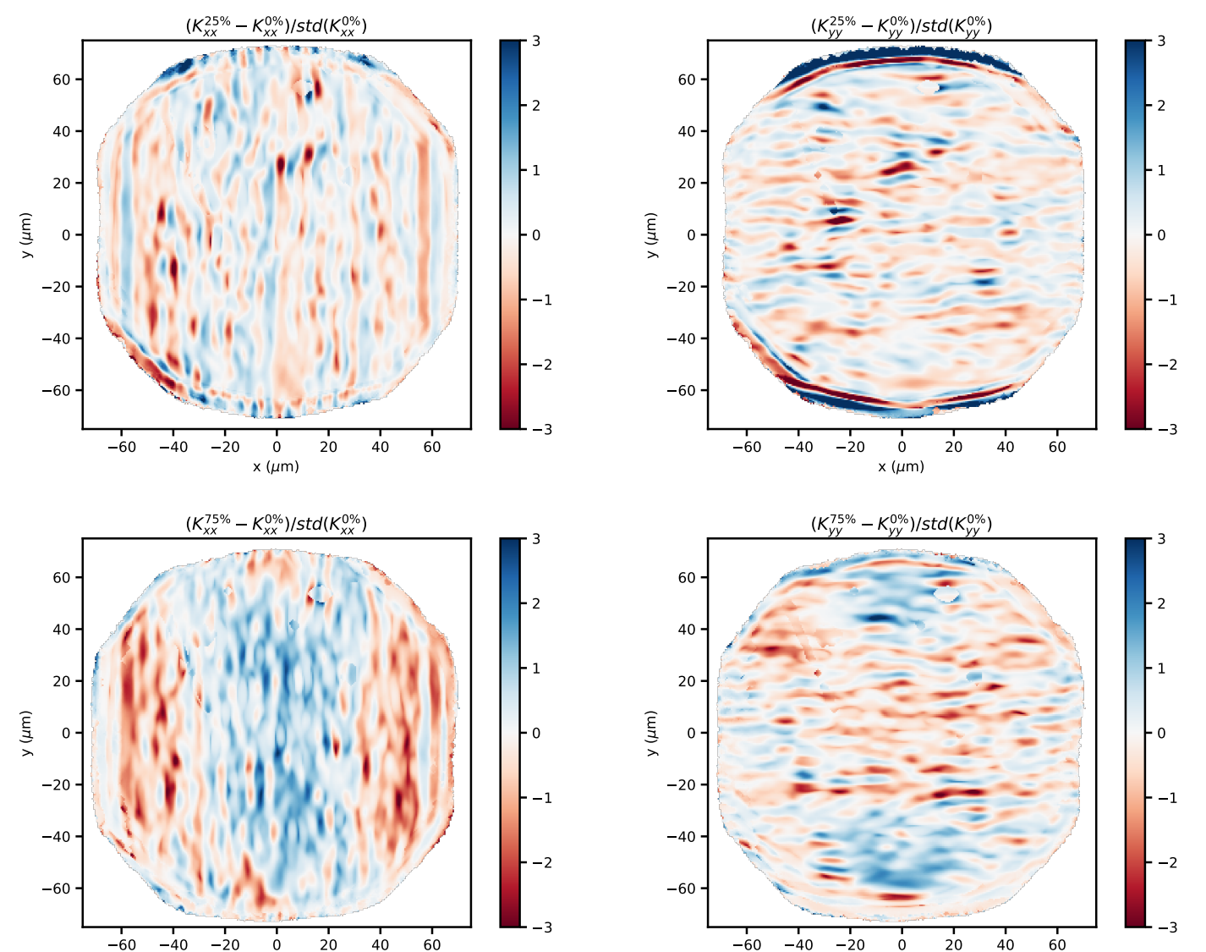
- Significant difference in height profiles due to membrane slotting and presence of Au absorber.
- Differences in curvature are small (devices are far from the membrane slots).

Small membranes



- 8x8 diagnostic test chip with identical TES (120 µm) and absorber, but with 0% (32 devices), 25% and 75% (16 each) membrane perforations.
- Measurements indicate a reduction in Tc with increasing perforation. Qualitative difference in Ic(B) suggests changes in current distribution.
- Could stress be responsible?



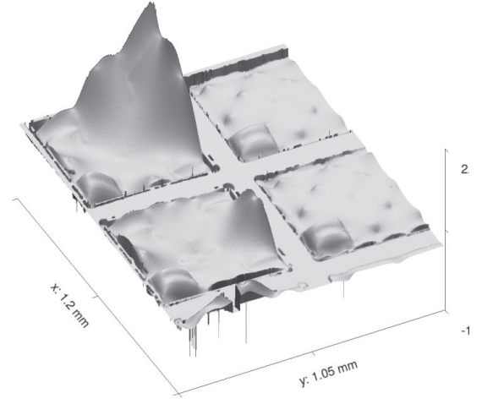


- 25% vs 0%: no systematic difference
- 75% vs 0%: clear systematic difference
- Further measurements are planned to confirm this correlation.

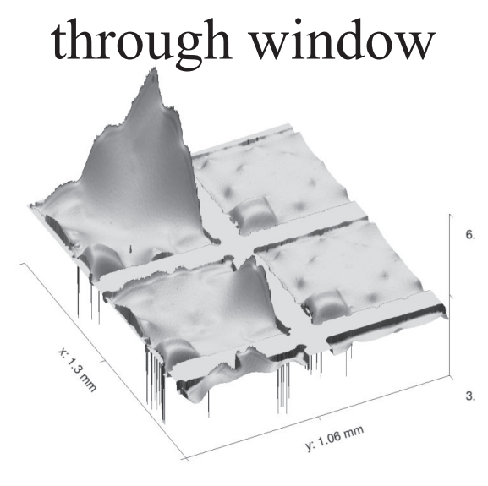
Profilometry on cold samples

- Thermal expansion mismatch between films expected to produce substantial additional stress: e.g. ~380MPa equibiaxial compressive stress for Mo vs. Si
- Planning to build a LN2 cooled cryostat with optical window to investigate temperature dependence.
- 2nd glass piece of identical thickness needed in interferometer reference arm to compensate for optical window
- Tested with 1 mm window on Micro-X [5] test chip. Height profiles agree.

no window



through window



Conclusions and future work

- Optical profilometry allows non-destructive membrane curvature measurement even in the presence of front metallization and absorbers
- In the devices studied here, curvatures at the TES are dominated by local metal layers (Nb contacts, banks/ fingers)
- For small devices, changes in membrane perforations can have a measurable impact on TES curvature
- Resulting stress distribution could lead to changes in current distribution as witnessed e.g.in Ic vs. B curves
- Unique determination of strain/stress state requires additional inputs: layer thickness, intrinsic stress, and elastic constants for other layers. We are planning to include additional diagnostic structures to determine these in future fabrications.