The impact of transition edge sensor design on achievable performance uniformity of kilo-pixel arrays

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Introduction

- Future astronomy missions using x-ray transition-edge sensor (TES) microcalorimeters, such as X-IFU on Athena, will require large arrays of 1000s of pixels fabricated on a single wafer. Barret et al., Proc. SPIE, 9905, (2016)
- To wire out so many pixels the current array designs have pixels with different rotational orientations.
- Fabrication is done in multiple layers and so, dependent on method, there is potential for spatial misalignment between layers.
- Because of the variation of orientation of pixels, misalignment may not impact each pixel equally.
- This has the potential to degrade the achievable uniformity of performance across an array.
- How well aligned do different layers need to be?
- How does sensitivity to misalignment depend on choice of pixel design?

Current kilo-pixel array design

- Pixels are wired out in 4 quadrants.
- Each quadrant wires out to a different side of the chip.
- This means there are 4 different rotational orientations of the pixels.
- Each of the center 4 pixels has a different orientation.

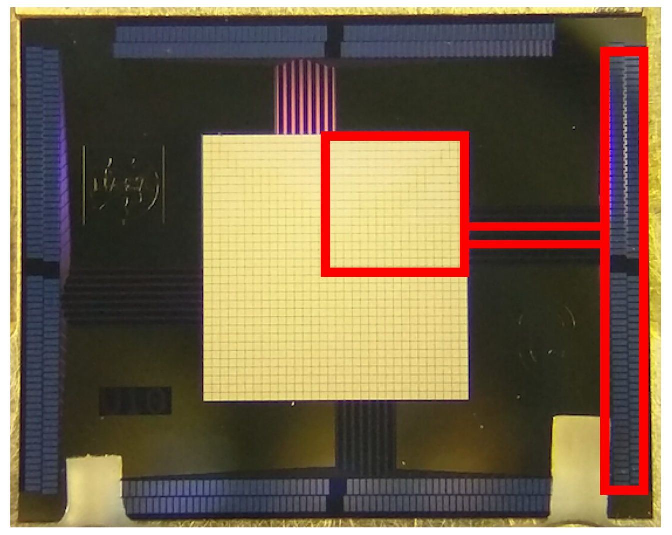
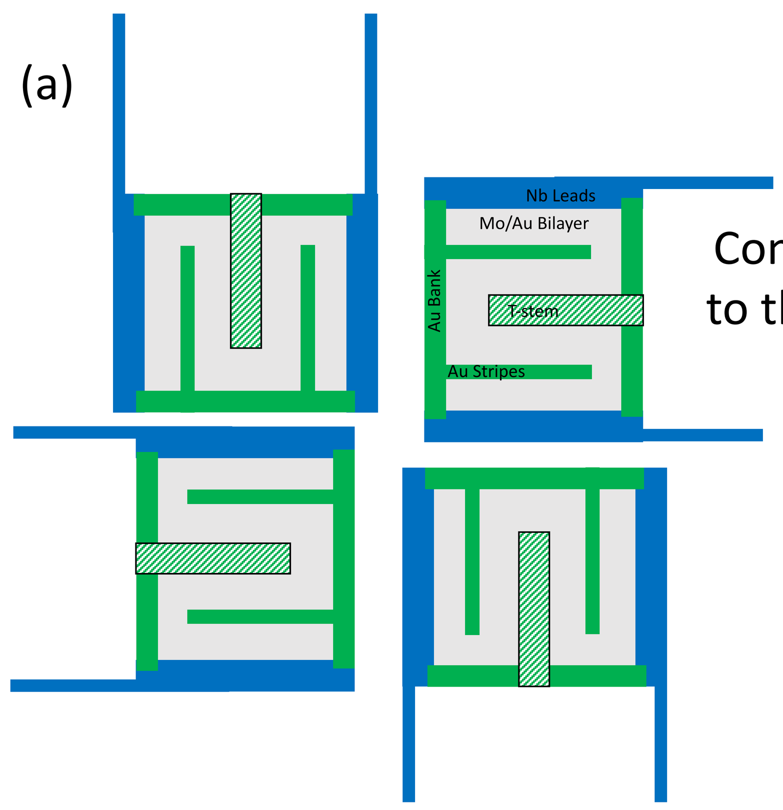


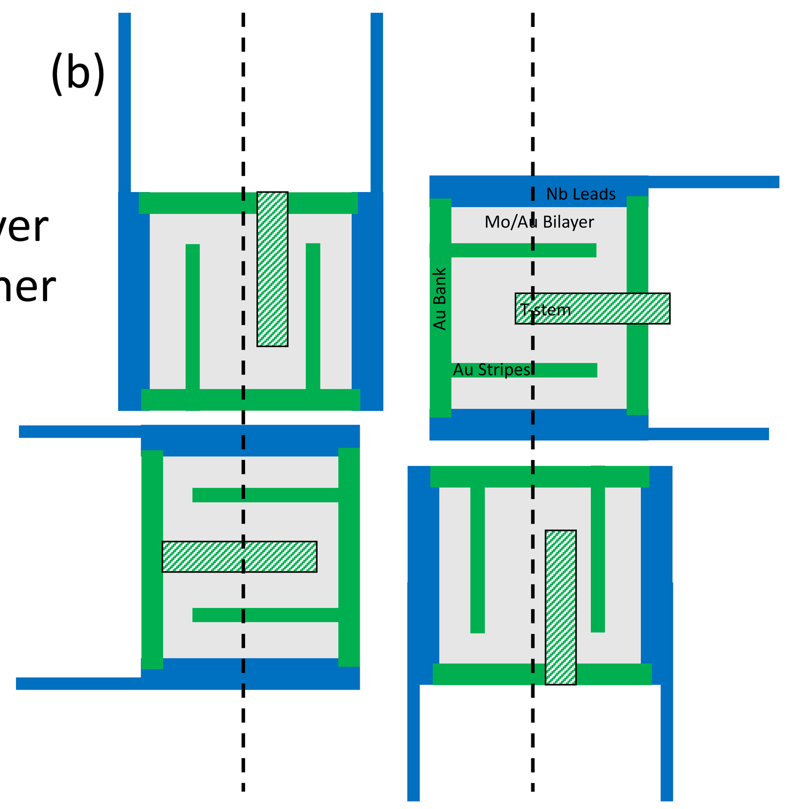
Fig. 1. Image of kilo-pixel array. Array is wired out in four quadrants each with a different rotational orientation. Red box highlights one quadrant.

(a)



Consider shift of stem layer to the right relative to other layers.

(b)



If the mask alignment is perfect all pixels are identical

If there is a misalignment, for example in stem layer, this may affect each orientation differently.

Fig. 2. Schematic diagram showing the four central TES pixels (absorbers not shown) in our current kilo-pixel array design. TES's have Mo/Au bilayer (light gray) connected with Nb leads (blue), Au banks parallel to the current direction and two Au stripes perpendicular to current direction (solid green), and a large "T-Stem" attachment between the absorber and TES (hashed green). Fig 2(a) shows perfect layer alignment. (b) Shows effect of misalignment of T-stem layer to the right.

Example of mask misalignment in striped devices

Tc variation

- In misaligned wafer, measured transition properties of a kilo-pixel TES array with normal metal stripes and "T-stem" (Fig 2).
- Expect a smooth T_c gradient ~1mK across a chip from small thickness variations in bilayer.
- In this array with stripes we also measured a step change in T_c ~0.5mK between quadrants (Fig. 3).
- This is an extreme example but such quadrant dependent T_c (and transition shape) observed in other striped device arrays.
- Electron microscopy indicated a shift of the stem layer by 2μm (Fig. 4). All other layers appear aligned to better than 1μm.
- T_c shift agrees with order of magnitude estimates from calculations of 2μm change of separation between stem, stripes and banks.

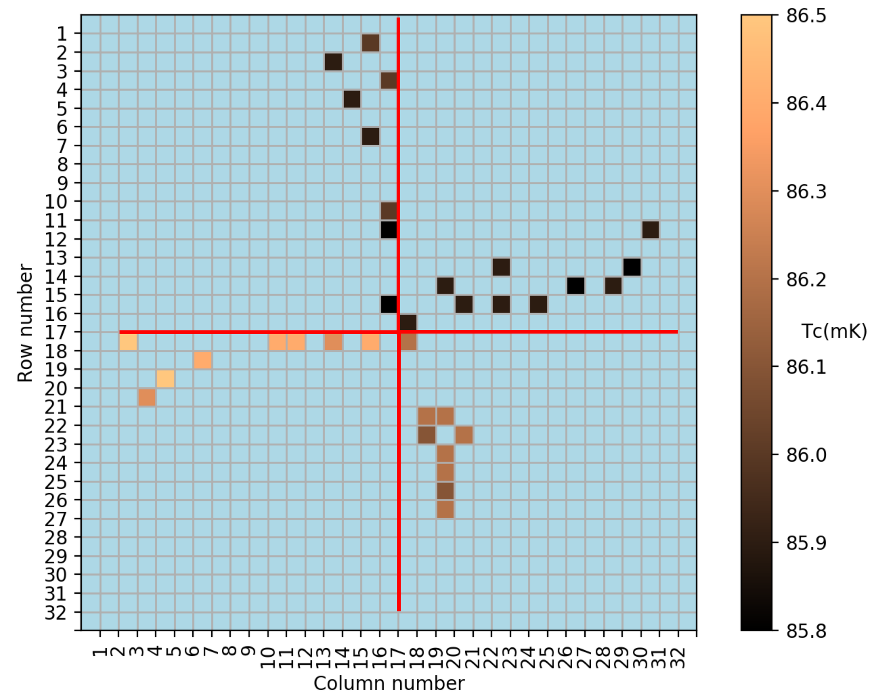


Fig. 3. Map of measured low current T_c across misaligned kilo-pixel array. Blue squares are unmeasured. Red lines divide up four quadrants and therefore four pixel orientations. Note the step like change in T_c at the center .

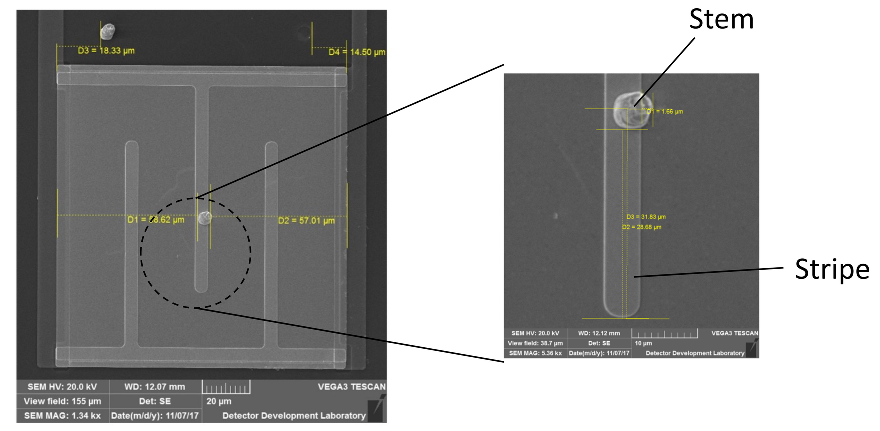


Fig. 4. Scanning electron microscope images of diagnostic pixels on wafer. Shows stem layer (light gray dot) is misaligned from stripe layer (darker gray).

Transition shape variation

Also see a step like change in shape of transition of resistance R with temperature T of pixels in different quadrants.

Shown here as $\alpha_{IV} = \frac{T}{R}\frac{dR}{dT}$

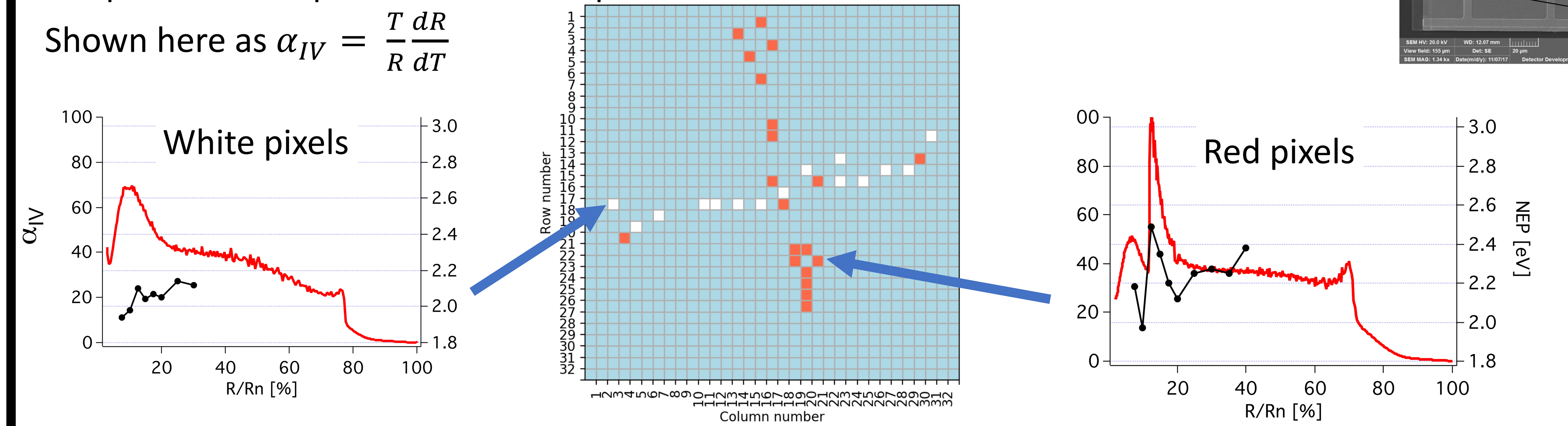


Fig. 5 Map showing type of transition shape across array. Red pixels have sharp 'kink' like transition shape (right). White pixels have smooth transition (left). Measured NEP also shown for each pixel type.

No-stripe TES arrays

- Arrays of TES's without stripes have not shown this quadrant dependent variation in Tc or transition shape.
- Consistent with previous work that showed transition shapes in striped devices may be more sensitive to parameter changes than devices without stripes.

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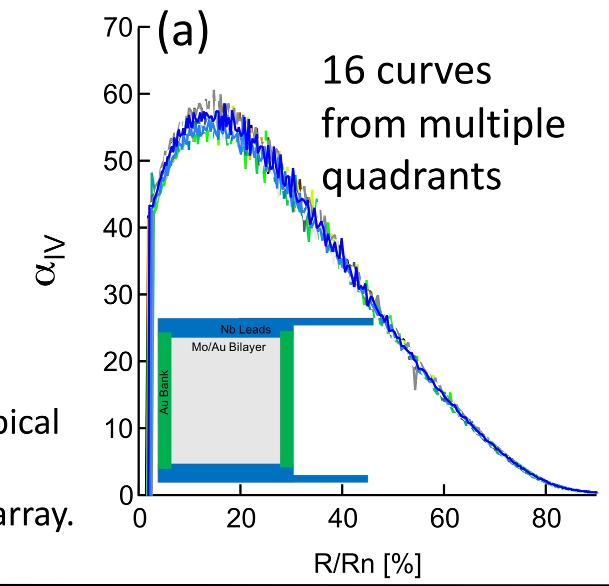

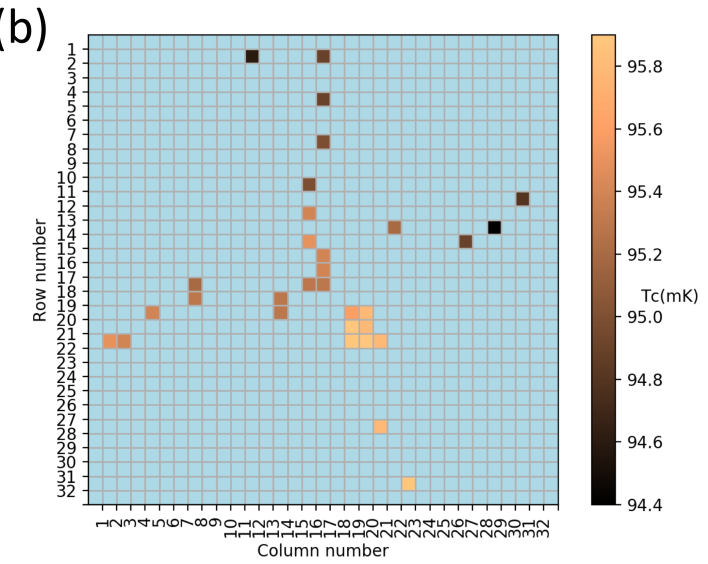

Fig. 6. Data from no-stripe TES arrays (a) Typical α_{IV} uniformity measured across multiple quadrants. (b) Map of T_c across a no-stripe array.

Conclusions and Future Work

- Array scale non-uniformity may indicate need for a new fabrication approach in striped TES devices.
- Kilo-pixel arrays of devices without stripes show smoother, more uniform transition shapes.
- In the future we will test devices fabricated with systematically varying misalignments of different layers to quantitatively test sensitivity of different TES designs.