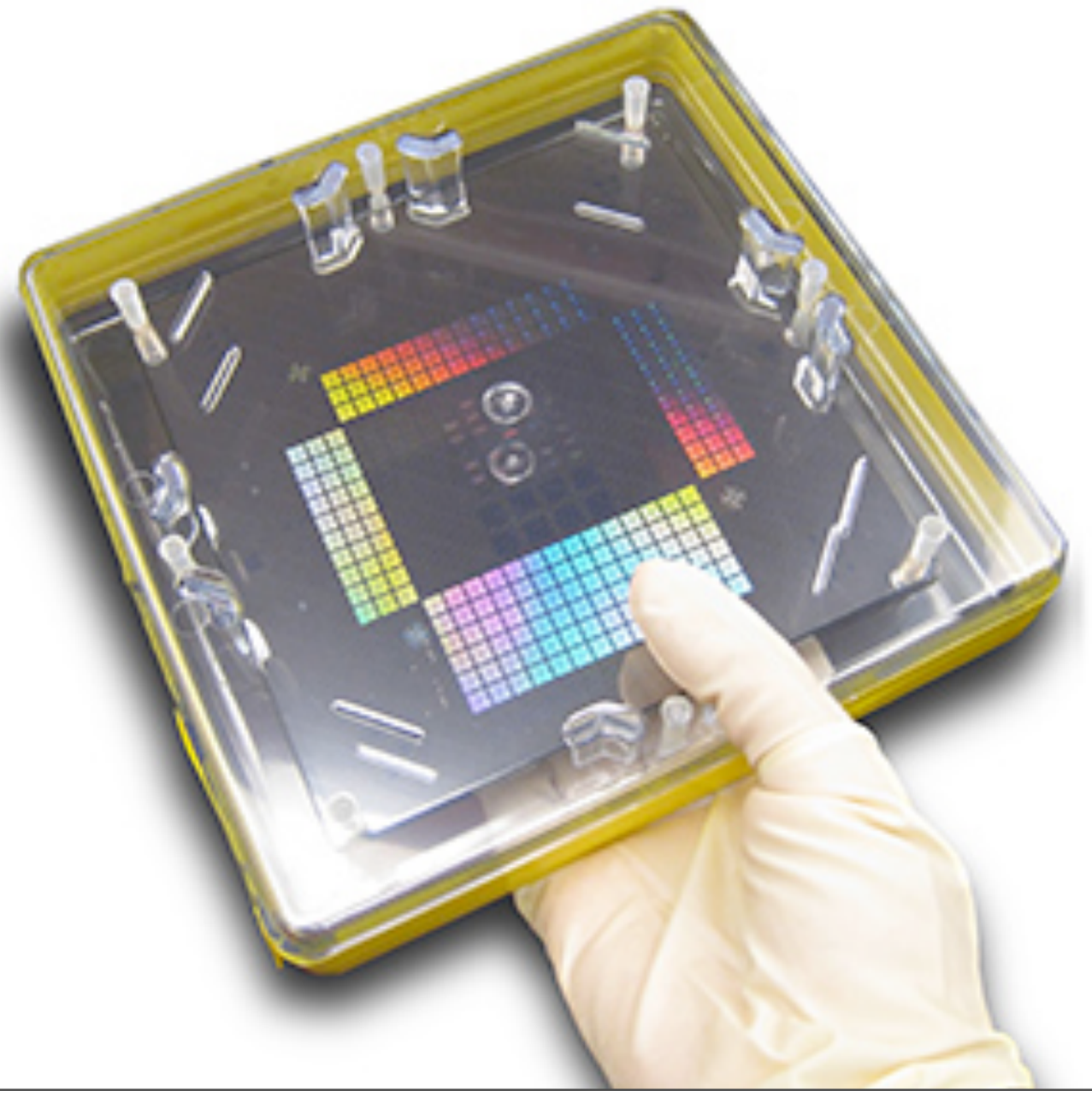
Planning Successful Experiments on the SEMATECH Berkeley AIT

Prepared by K. Goldberg, 4/20/2010

Planning Successful Experiments on the SEMATECH Berkeley AIT

- Experiment Preparation Checklist
- AIT Fact Sheet
- Instructions for **blank masks**
- Instructions for **patterned masks**



Experiment Planning

REMEMBER:

- **The AIT is a research prototype tool.**
  It is not like a normal microscope.

WORK WITH THE AIT TEAM

- **When planning experiments,** to ensure success, we recommend that you consult with us *as early as possible*. Based on our experience, we will recommend strategies to ensure the best results with the most efficient AIT measurements possible.
- **We are very happy to help you** to develop **new testing ideas**, **mask designs** that facilitate measurement, and **experiment plans** that are easy to follow.

AIT Strengths and Weaknesses

What the AIT is best at doing:

- **Line & pattern properties** (including architecture):
  through-focus NILS, CD, LWR, Contrast, OPC, etc.
- **Programmed defect arrays**: imaging & characterization
  Defects positions must be clearly marked.
- **Native pattern or substrate defect** imaging & characterization
  Defect positions must be clearly marked, or the pattern navigable (i.e. we can locate the defect position with certainty).
- **Mask-blank defect imaging** & characterization
  Defects must be marked.
- **(New) Aerial image *complex amplitude*** *(Please discuss with us.)*
- **Measurements with adjustable NA** = {0.0625, 0.0800, 0.0875}
  Like 4× NA = {0.25 (ADT), 0.30, 0.35};
  Like 5× NA = {0.31 (close to MET), 0.38, 0.44}

AIT Strengths and Weaknesses

Key Challenges for the AIT:

- Challenge: Finding isolated defects (due to its lack of kinematic mask loading, lack of *in situ* visible microscope, *x*θ stage, and unknown coordinate offsets)
- Challenge: Finding pattern defects without nearby reference marks (i.e. pattern defects without nearby markers)
- **Let's be clear: AIT does not have a reliable mask coordinate system and cannot accurately use fiducials in the corners of the mask.**
- We use the mask pattern itself, or fiducial marks to align our coordinates. That alignment works well over limited distances mm–cm.
- AIT cannot image the mask (n*or find fiducials*) outside of 50-mm radius.
- An impossible request: Find the tiny, isolated defect at *xy* = (1.23, 4.56)
- 30-µm field of view; 3–8-µm sweet spot (NA dependent)
- Low sigma value, $\sigma \approx 0.15$ (i.e. moderately high coherence)
- Challenge: Images need intensity normalization to achieve uniformity.
- AIT has no calibrated way to measure mask reflectivity, to compare masks.
- Finding focus is challenging without a reference mark, even in dense lines.

AIT Experiment Checklist

Mask Packaging

- For blank masks, or masks with a symmetric pattern, make sure the orientation of the mask is clear, by eye, so we know how to load it into the AIT.

Shipping

- Ship the mask to LBNL so that it arrives a few days in advance.
  (LBNL Receiving can be slow sometimes.) Instructions: http://AIT.lbl.gov/shipping.php
- Email the tracking number and updates to Ken and Iacopo.

Experiment Plan

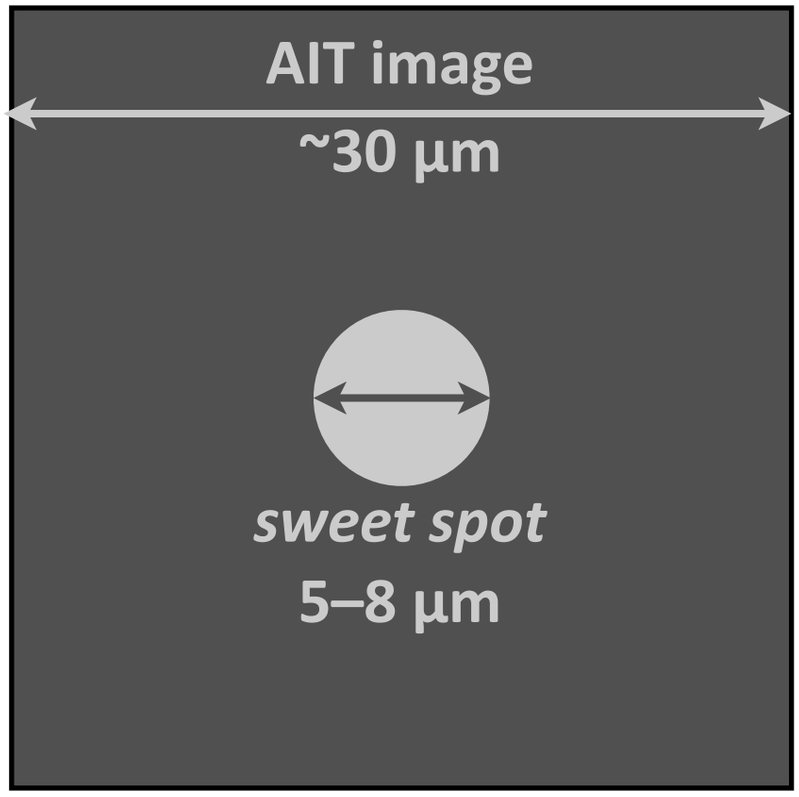
- Prepare and send us a **detailed experiment plan** as early as possible.
  In email, please always use the **mask serial number** or **specific name**
  ("BFD-570312" or "MET-RGM3" is better than, "the defect mask.")
- List the measurement points, starting from the *highest priority*.
- Make sure to include the desired **imaging conditions**
  1. **Mask-side NA** {0.0625, 0.0800, 0.0875}, we have 3 zoneplate lenses we commonly use.
  2. **Through-focus step size** (0.4 or 0.5 µm is typical). Smaller NA can use larger steps.
  3. The number of steps through focus or the **through-focus *z* range** (total range or ±)

(*More detailed information follows*)

AIT Fact Sheet (1)

GENERAL INFORMATION

- **6” MASKS:** The AIT only measures reflective EUV masks (6-inch square, 1/4-inch thick).
- **EUV ONLY:** The AIT does not have a built-in visible-light microscope or a low-magnification mode. We can only inspect the mask using our 907x magnification, EUV zoneplate lenses. We do have a visible-light microscope in the AIT cleanroom.
- **VIEWABLE AREA:** The viewable area in a single AIT image is approximately 30-µm wide.
- **SWEET SPOT:** The imaging *sweet spot*, where the aberrations are minimized, is near the center of the field, and is approximately 5–8 µm diameter (depending on the NA).



AIT Fact Sheet (2)

GENERAL INFORMATION (continued)

- **STABILITY:** During inspection, our vibration quenching system gently touches the surface of the mask approximately 2.5 cm away from the image point, in the radial direction, away from the center of the mask.
- **AIT Coordinates:** The AIT does not have kinematic, repeatable mask loading or positioning. We typically use **known positions on the mask** pattern to calibrate our coordinate system's (Δx, Δy) offset. For this reason, it is very important for us to have clear instructions about the locations (x,y) of major pattern features (corners, edges, etc.) that can be found easily and which are close to the measurement positions.
- **AIT $x\theta$ Mask Stage:** The AIT mask stage is a $x\theta$, translation and rotation. To measure a point on the mask, we rotate and translate the mask under the fixed beam position. Therefore, the mask pattern will appear rotated in the raw data. Also, there is one point at the center of rotation that is difficult to reach. That point is usually within a few mm of the mask center.

AIT Fact Sheet (3)

GENERAL INFORMATION (continued)

- **Measurement Area:** The AIT can only measure the central portion of the mask, as shown. The area is limited to about 50 mm radius—a little more in the 45° directions.

IMAGING CONDITIONS

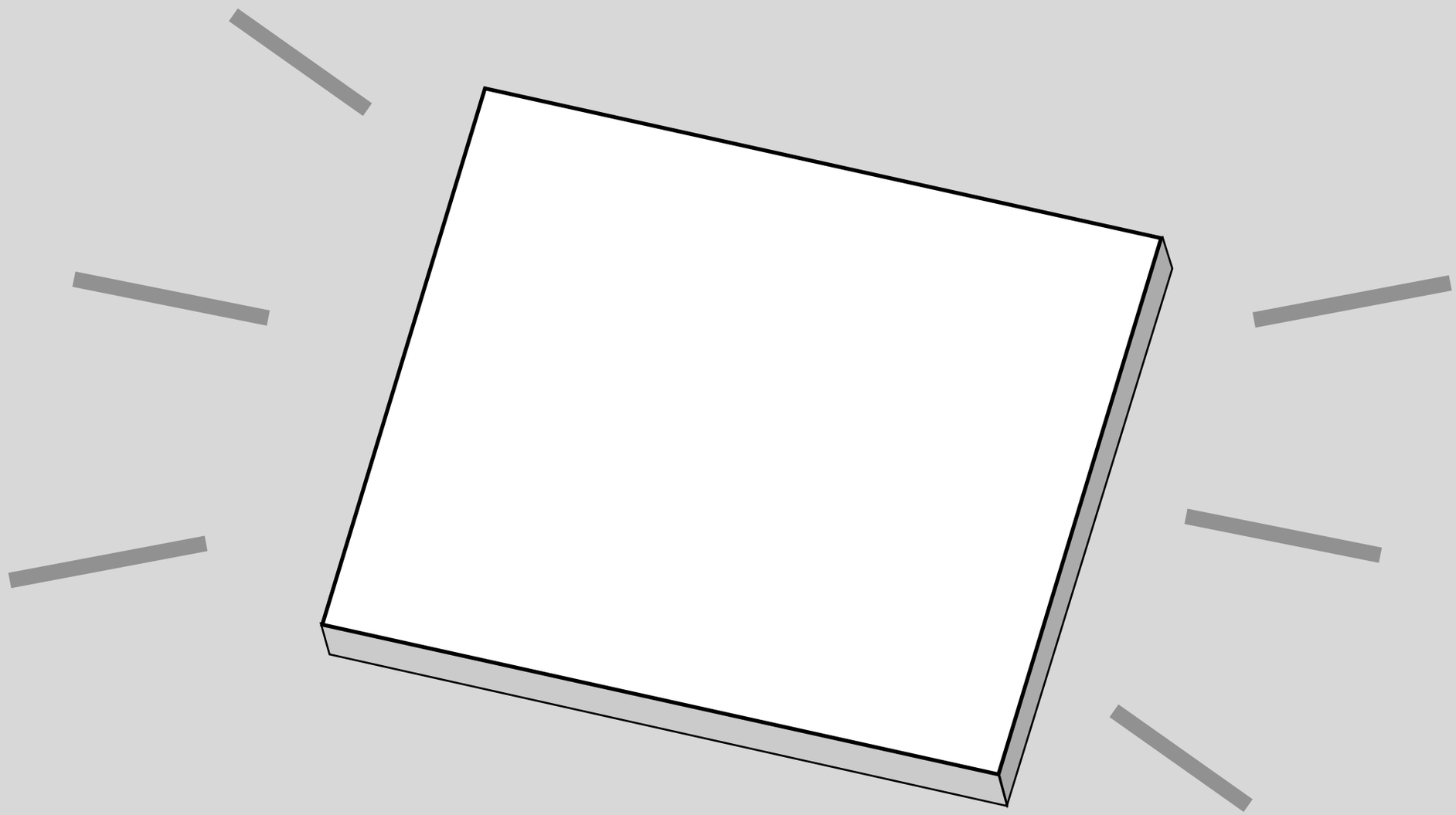
- There are **3 primary zoneplates** in use on the AIT.
  "B": 907x, 0.0625 NA (mask-side), 0.25 NA (4x)
  "C": 907x, 0.0800 NA (mask-side), 0.32 NA (4x)
  "D": 907x, 0.0875 NA (mask-side), 0.35 NA (4x)
  We can easily switch zoneplates. The zoneplate that most closely matches the ADT is **"B"**.
  The zoneplate that most closely matches the mask-side resolution of the MET is also **"B"** (0.0625 AIT vs. 0.06 MET)
- **Δ*z* Step Size.** We can take through-focus steps as small as 0.4 µm Δ*z*. Divide by 16 to calculate the ADT equivalent step size. Divide by 25 for the 5x MET. Small features (< 100 nm) need 0.4 or 0.5 µm. Large features (> 100) can use larger steps to save time. This is based on the *depth of focus* vs. CD.

AIT Fact Sheet (4)

SHIPPING

- **Online Instructions:** Detailed shipping information is available here: **http://AIT.lbl.gov/shipping.php**
- **Early:** When shipping the mask, it is important to send it a few days **early**, to avoid possible delays and lost time.
- **"Overnight":** LBNL's receiving department can be slow. Overnight shipments may not reach us until the afternoon.
- **Tracking #:** Always email tracking to **KAGoldberg@lbl.gov** and **IMochi@lbl.gov**
- **"Samples":** Always write, **"Sample for Measurement"** in the comment field. This is especially important for US Customs (international shipments). It is also important to speed up package delivery within LBNL.
- **Mask Name:** It is helpful to put the mask name or serial number in the *comment field* of the package-tracking emails (e.g. "Mask IMO113715").

Advice for
Experiments with Blank Masks

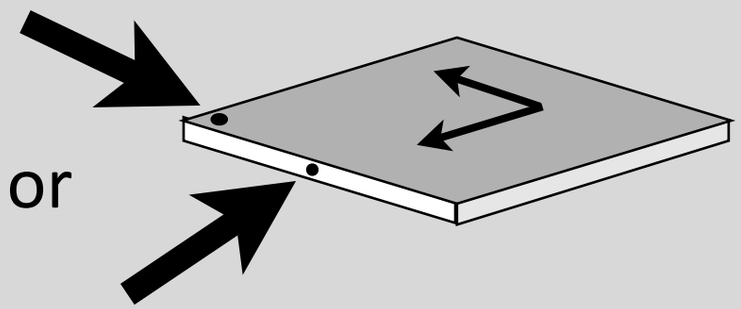


Experiments with Blank Masks (1)

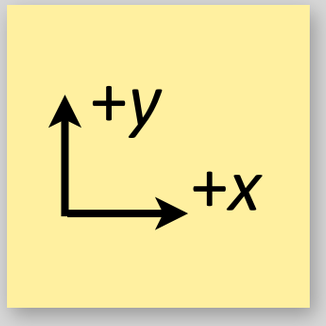
MASK ORIENTATION

- **Tell us +*y* or +*x*:** The AIT does not have a built-in visible-light microscope. If we don't know the rotation of the mask, we can lose time searching the wrong location! Please show us which direction is **+*y***. You can

  1) Make a sharpie mark on the side or top of the mask:



  2) Write a note on the mask box showing:

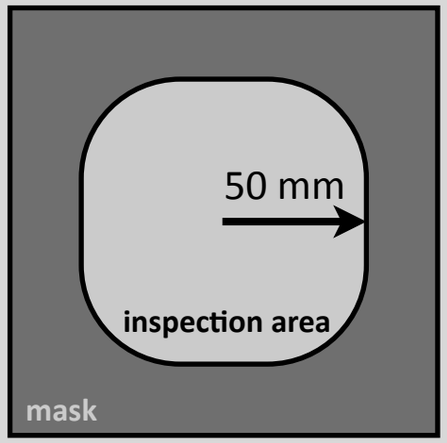


  3) Any other method that is clear to us.

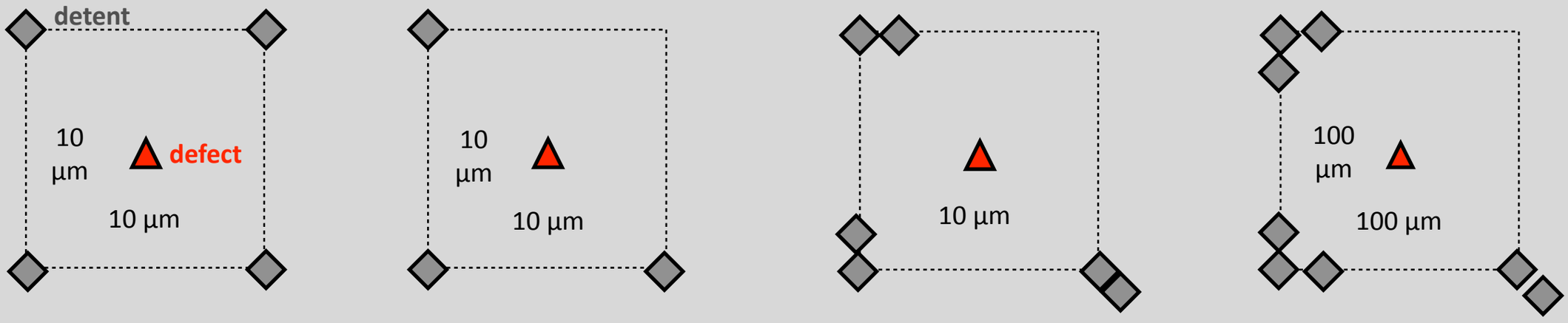
Experiments with Blank Masks (2)

IDENTIFYING DEFECTS

- **Tell Us +*y* or +*x* orientation:** The AIT does not have a built-in visible-light microscope. If we don't know the rotation of the mask, we can lose time searching the wrong quadrants.
- **Measurement Region:** Choose defects inside the AIT's inspection area.



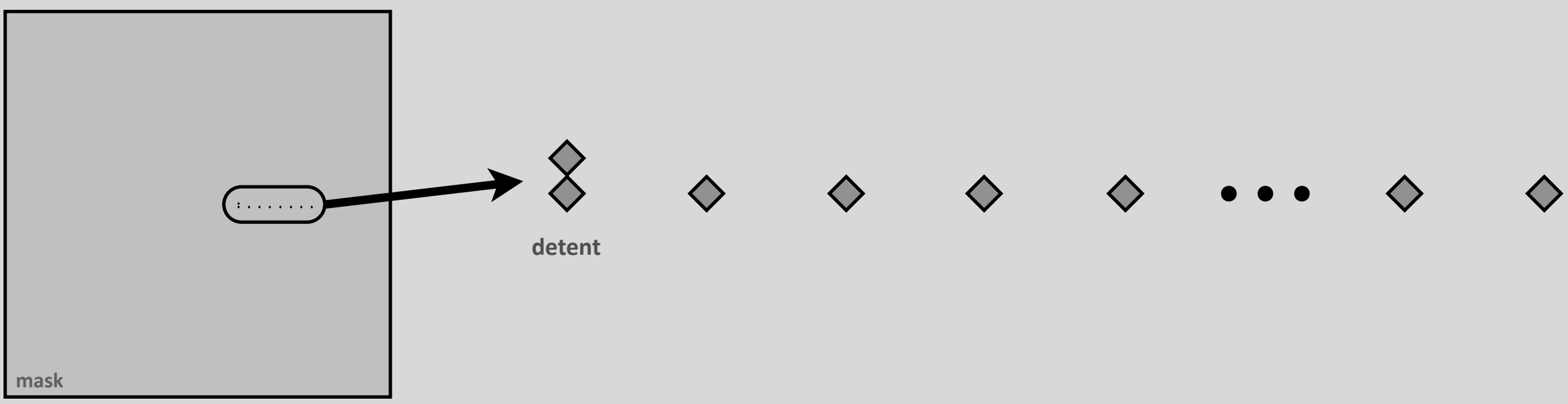
- **Marking Defects:** Defects can be incredibly hard (and time consuming) to find. There have been several successful strategies that have been used to highlight defect locations and make them easier to find in the AIT. These strategies use detents (5–10 µm) near the defects.



Experiments with Blank Masks (3)

FINDING THE FIRST DEFECT

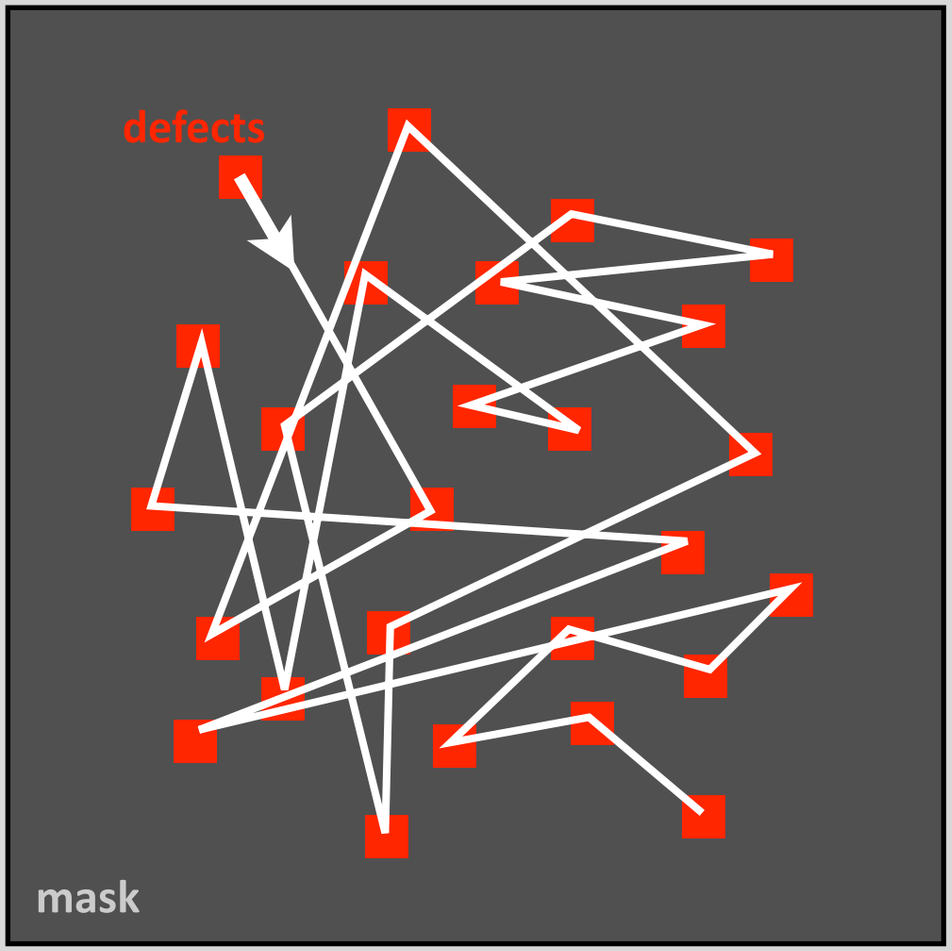
- **Finding the first defect's location is the most difficult task.**
  It takes the AIT about 1 hour to search a 1-mm-radius region.
- If we could reduce the search from 2D to 1D we could save time. One idea is to put a line of detents on the mask to serve as an easy to find reference.
- For example, with a line of detents spaced by 50 µm, the end of the line marks a known 2D (*x, y*) location. This is just one possibility. Having a long line makes it very easy for us to quickly find the *y* position, then we move along the line to find *x*. This is much better than the 2D, two-unknown scenario that we call "golf at night."



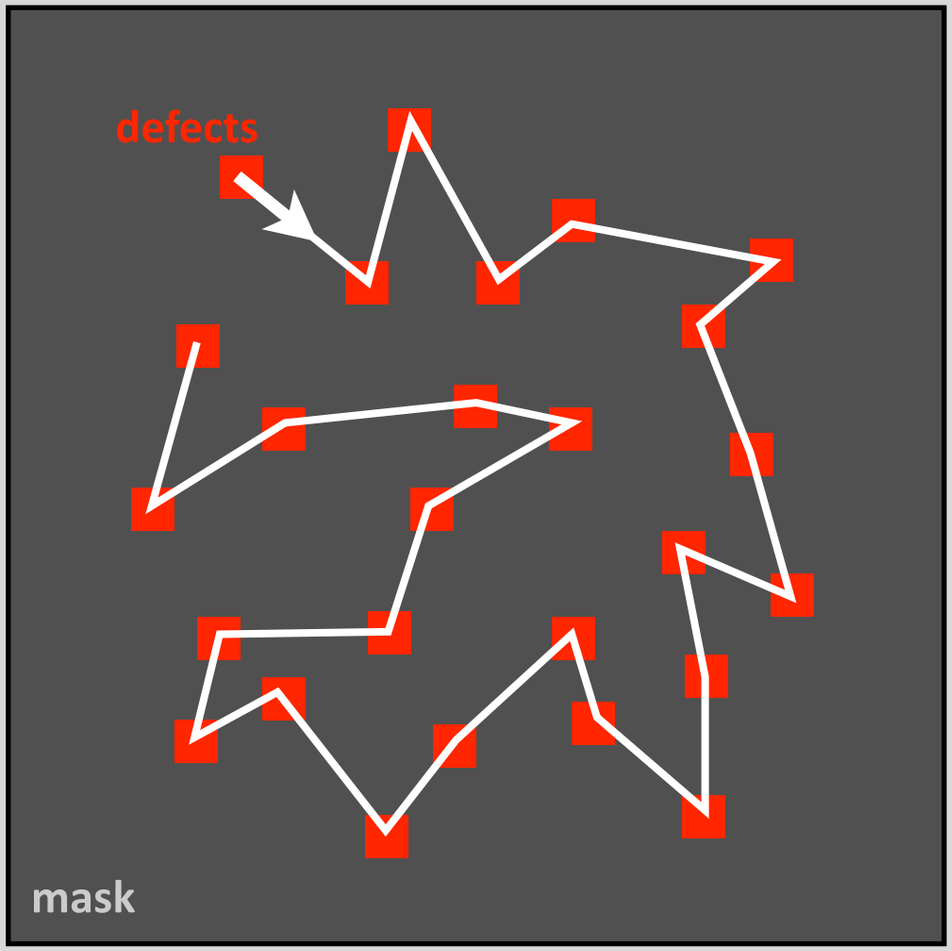
Experiments with Blank Masks (4)

ASSIGN PRIORITY

- **Rank The Defects:** Please list the defects so we know which ones are most important and we can measure those defects first.
- **Plan a Measurement Path:** The most efficient navigation for the AIT is to measure points that are close together. When we move a large distance, we may lose time searching for the defects.



A difficult measurement path



A better measurement path

Experiments with Blank Masks (5)

DEFECT COORDINATES

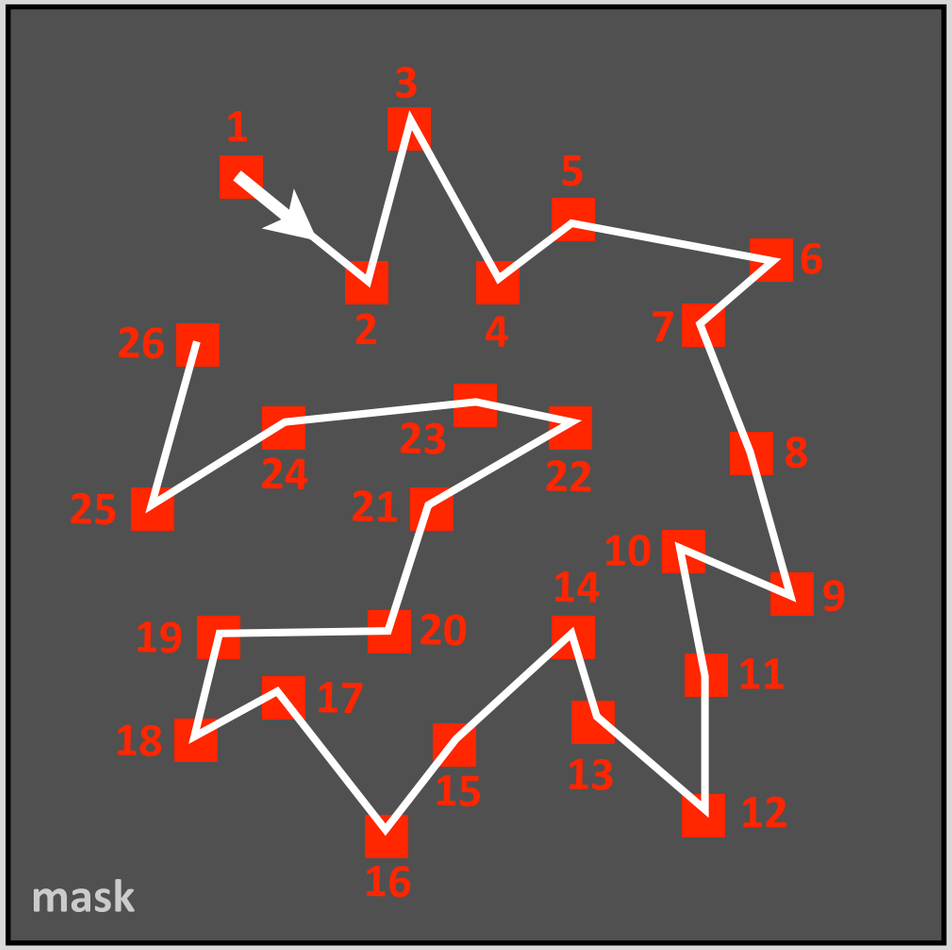
- **Spreadsheet or defect list:** If possible, please give us a clear list of the defects, names, sizes, and coordinates.

Workbook1

	A	B	C	D
1	Defect Number	Size	x [mm]	y [mm]
2	1	4	2.234	3.421
3	2	3	4.345	1.652
4	3	5	1.234	-0.117
5	4	6	8.456	-1.886
6	5	2	3.432	-3.655
7	6	3	-9.567	-5.424
8	7	1	-5.234	-7.193
9	8	4	-5.212	-8.962
10	9	2	-7.232	9.269
11	10	5	-8.344	7.500
12	11	6	2.234	5.731
13	12	3	7.345	3.962
14	13	1	1.345	2.193
15	14	10	-0.424	0.424
16	11	4	-2.193	-1.345

Sheet1 Sheet2 Sheet3

Ready Sum=0



Experiments with Blank Masks (6)

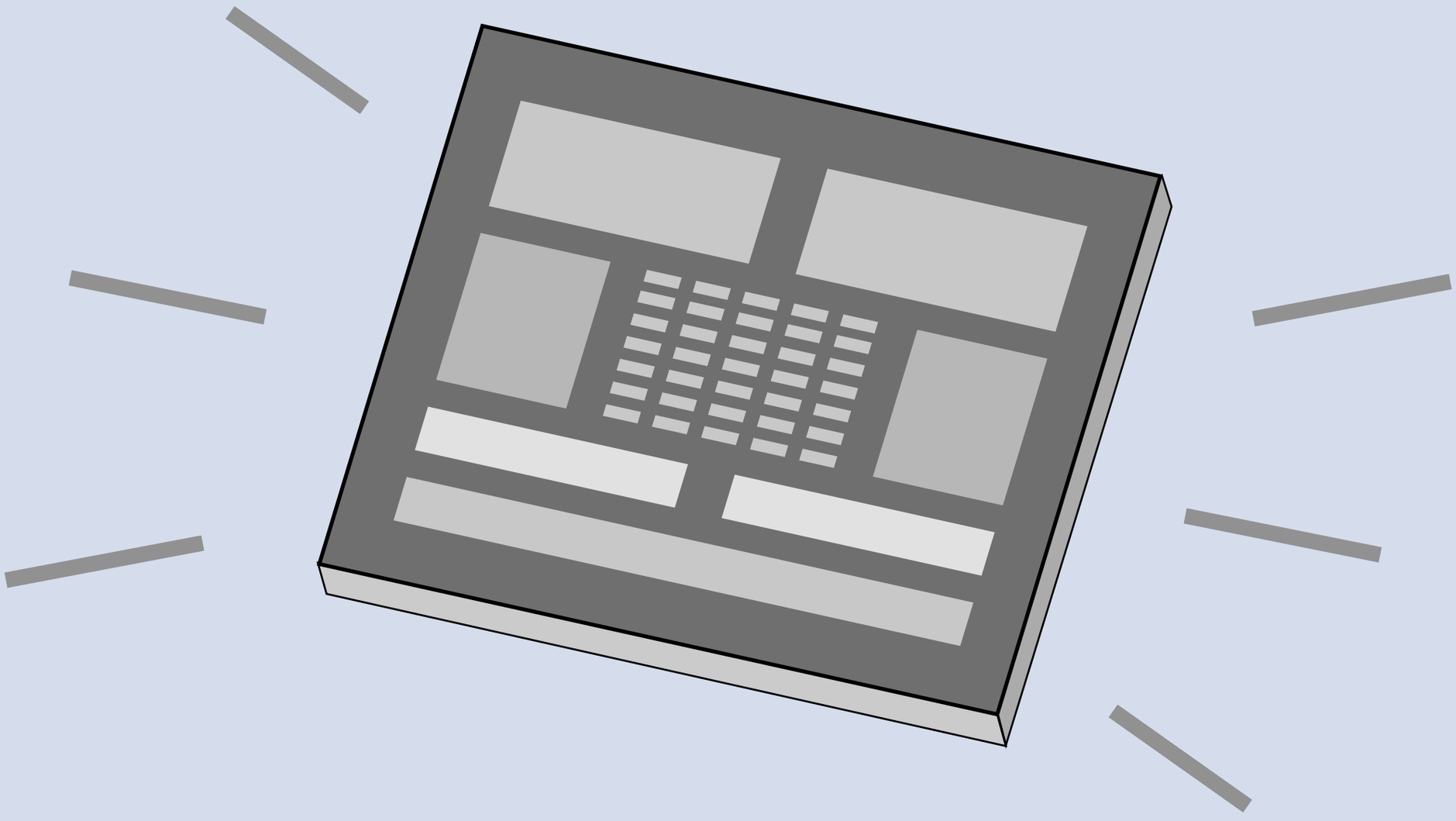
IMAGING CONDITIONS

- **Zoneplate:** Please specify the zoneplate:
  {B, C, D} = {0.0625, 0.080, 0.0875 NA} = {0.25, 0.32, 0.35 NA (4x)}
- **Through Focus Step Size:** Δz = 0.4 or 0.5 µm is typical.
  Smaller NA can use larger steps. Divide by 16 to calculate the ADT equivalent step size. Divide by 25 for the 5x MET.
- **Focus Range:** The number of steps through focus, or the through-focus *z* range (total range or ±)

USING THE MASK'S NAME IN COMMUNICATIONS

- In email, or by phone, always use the **mask serial number** or **specific name** ("BFD-570312" or "MET-RGM3" is better than, "the defect mask.")

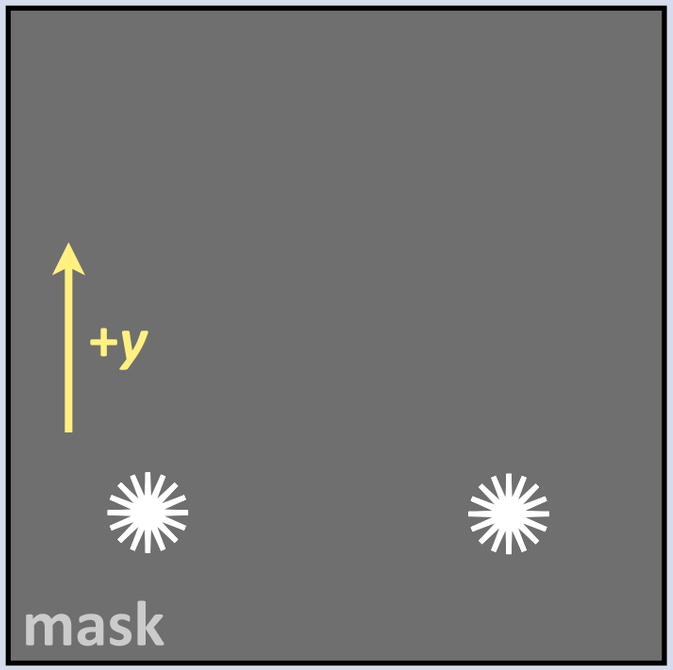
Advice for
Experiments with Patterned Masks



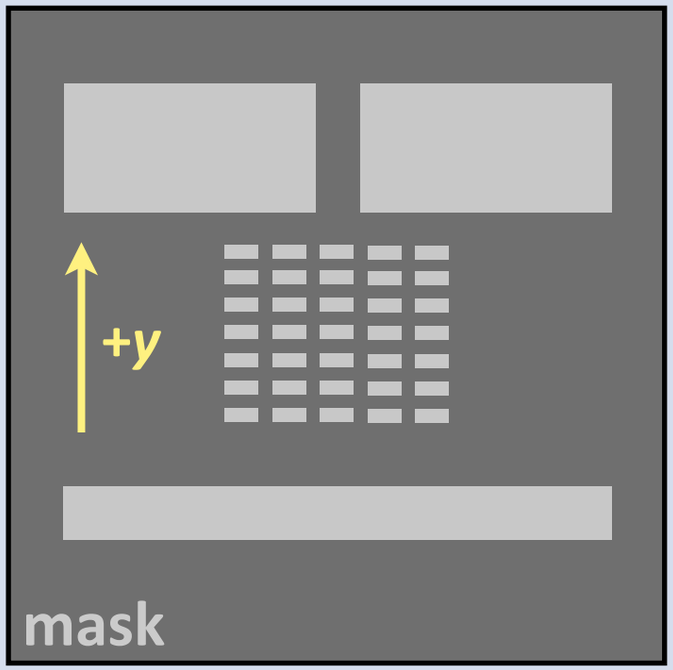
Experiments with Patterned Masks (1)

MASK ORIENTATION

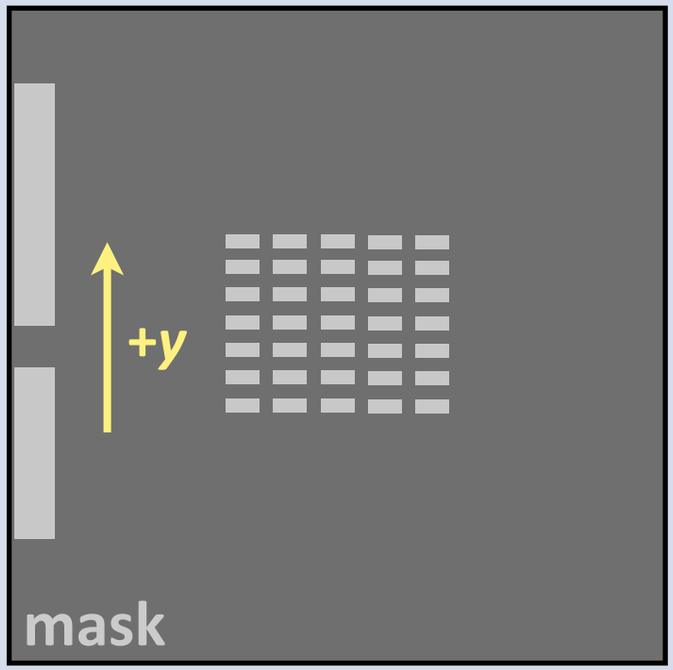
- **Tell us +*y* or +*x*:** The AIT does not have a built-in visible-light microscope. If we don't know the rotation of the mask, we can lose time searching the wrong location! Please show us which direction is **+*y***. You can



1) Show us the orientation of fiducial patterns



2) Show us the layout of large, easily-recognizable patterns

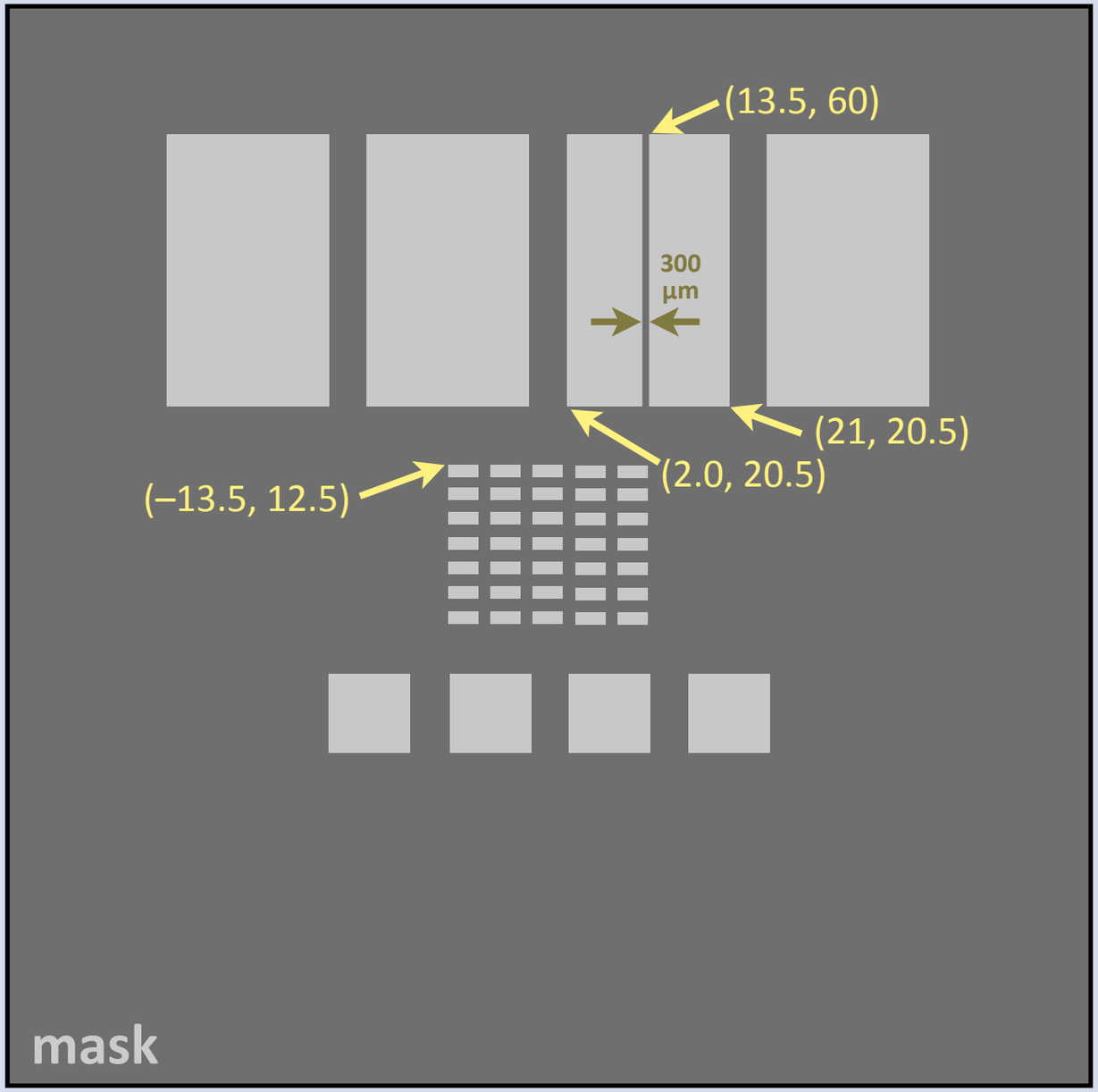


3) Show us the location of mask serial numbers

Experiments with Patterned Masks (2)

PATTERN AND CORNER POSITIONS

- **Tell us the (*x*, *y*) locations** of easily recognizable pattern features within the center portion of the mask. (Fiducials near the edge are not helpful!)
- Please use "mm" in mask units, **with respect to the mask center**.

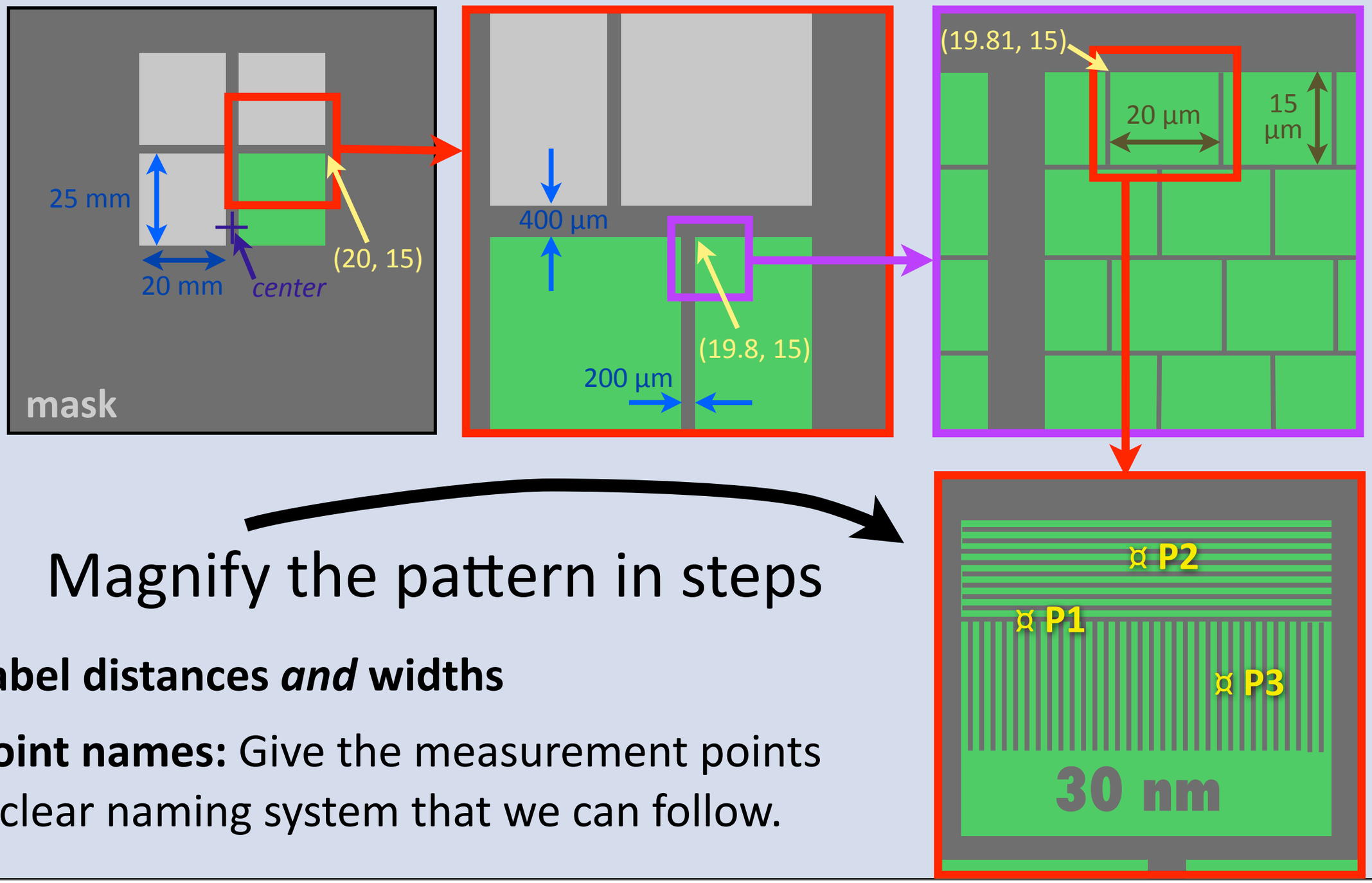


- Show us the positions of large, close features. Corners are most useful.
- Indicate the widths of narrow gaps or regions that we can find and use.

Experiments with Patterned Masks (3)

SHOW US A ZOOMED-IN VIEW

- **Save us time** by providing locations, sizes, and distances from features that are easy to identify. Zooming in steps helps us to navigate efficiently.



Magnify the pattern in steps

- **Label distances *and* widths**
- **Point names:** Give the measurement points a clear naming system that we can follow.

Experiments with Patterned Masks (4)

IMAGING CONDITIONS

- **Zoneplate:** Please specify the zoneplate:
  {B, C, D} = {0.0625, 0.080, 0.0875 NA} = {0.25, 0.32, 0.35 NA (4x)}
- **Through Focus Step Size:** Δz = 0.4 or 0.5 µm is typical.
  Smaller NA can use larger steps. Divide by 16 to calculate the ADT equivalent step size. Divide by 25 for the 5x MET.
- **Focus Range:** The number of steps through focus, or the through-focus *z* range (total range or ±)

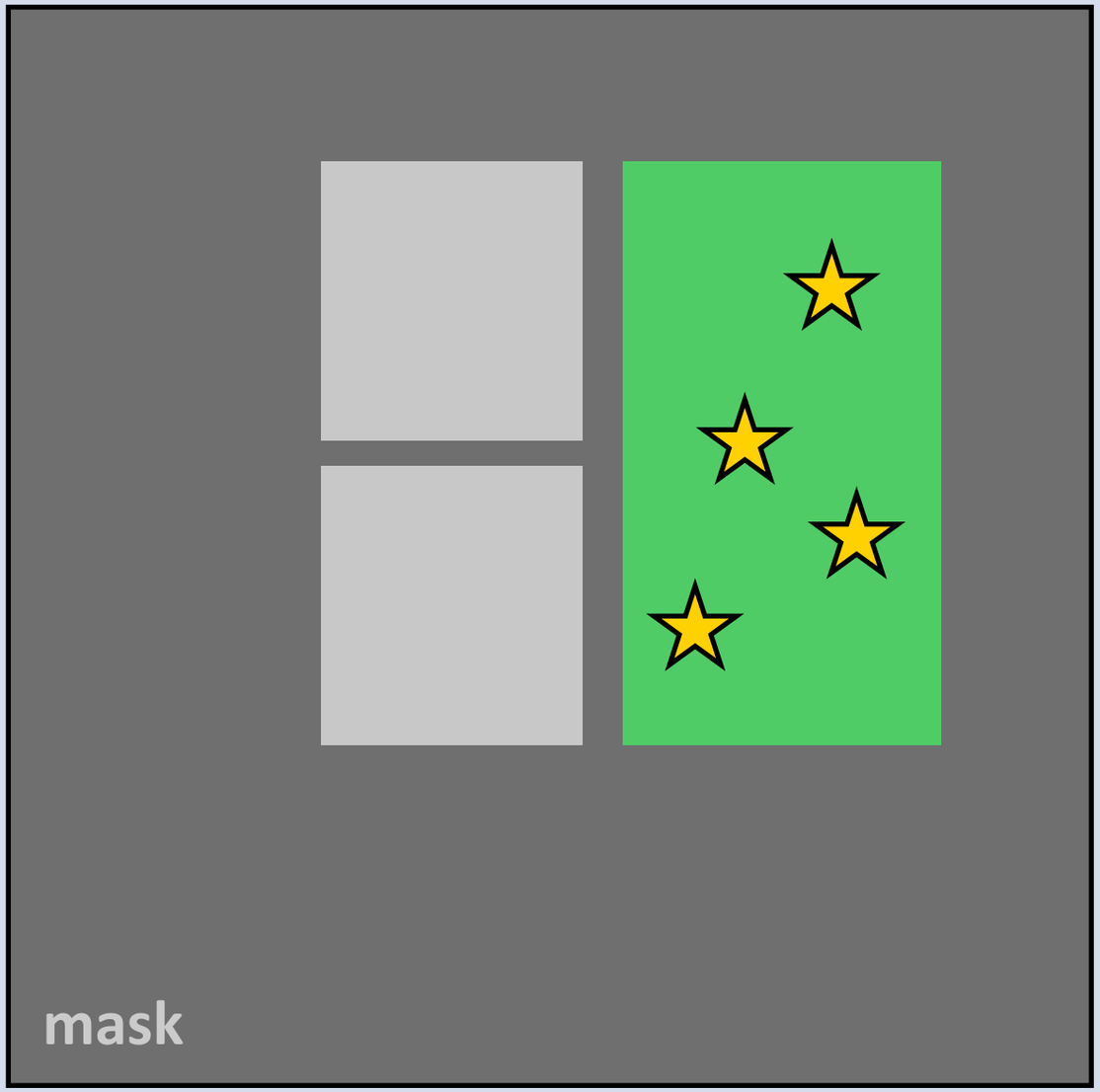
USING THE MASK'S NAME IN COMMUNICATIONS

- In email, or by phone, always use the **mask serial number** or **specific name** ("BFD-570312" or "MET-RGM3" is better than, "the defect mask.")

Experiments with Patterned Masks (5)

BAD EXAMPLE #1: ***WITHOUT REFERENCE MARKS WE CANNOT FIND THE DEFECT LOCATIONS WITH CERTAINTY.***

- **AIT navigation (Δx, Δy) is accurate only over a short distance**
- For example, this is an <u>impractical plan</u>



Please measure ☆

(x,y) = (15.123, 8.001)

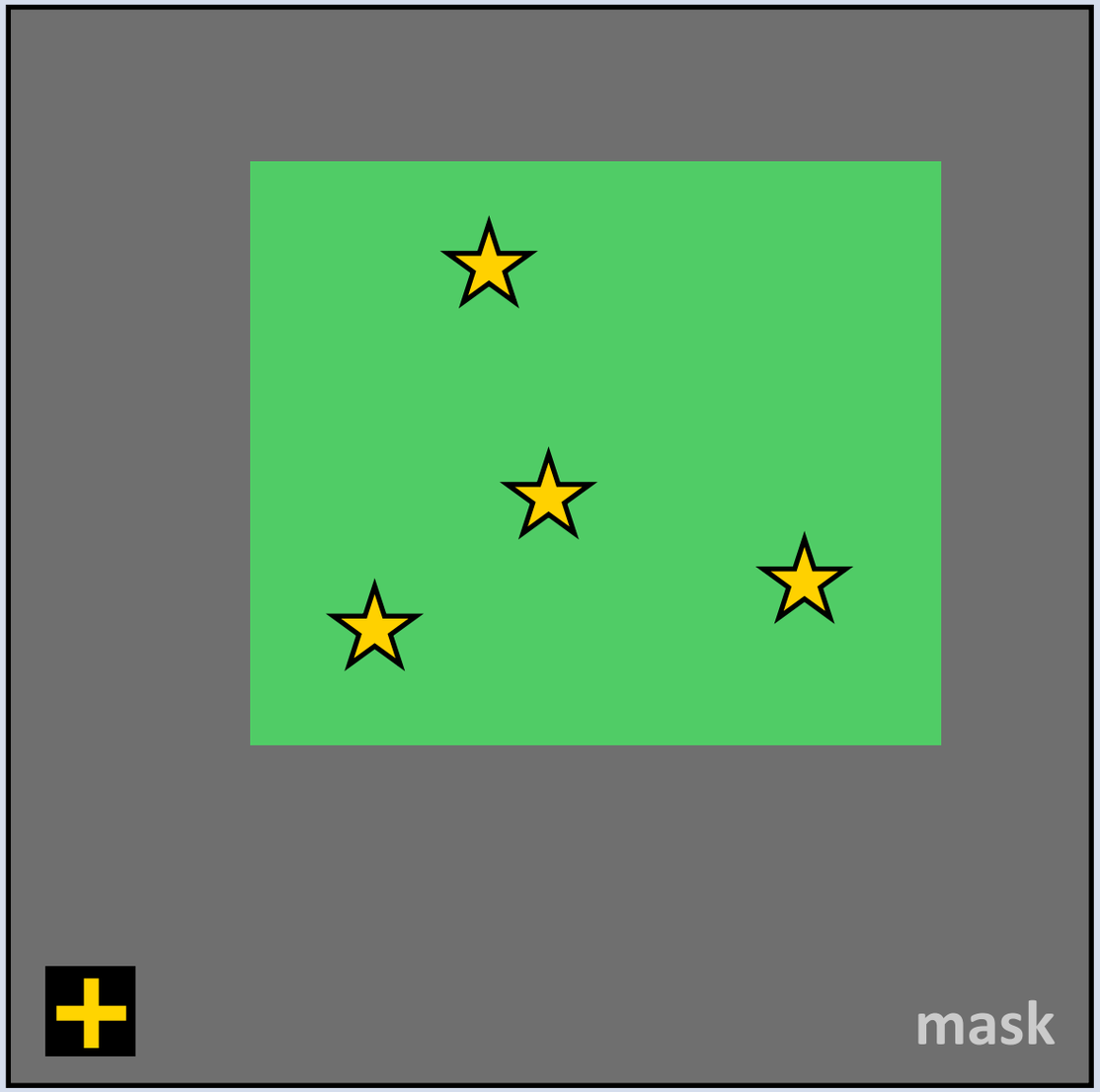
(25.789, 12.587)

(18.291, 35.212)

(28.570, 40.121)

Experiments with Patterned Masks (6)

BAD EXAMPLE #2: ***FIDUCIAL MARK IS TOO FAR AWAY***



Find defects ☆ with respect to fiducial ✚

(x,y) = (30.123, 40.001)

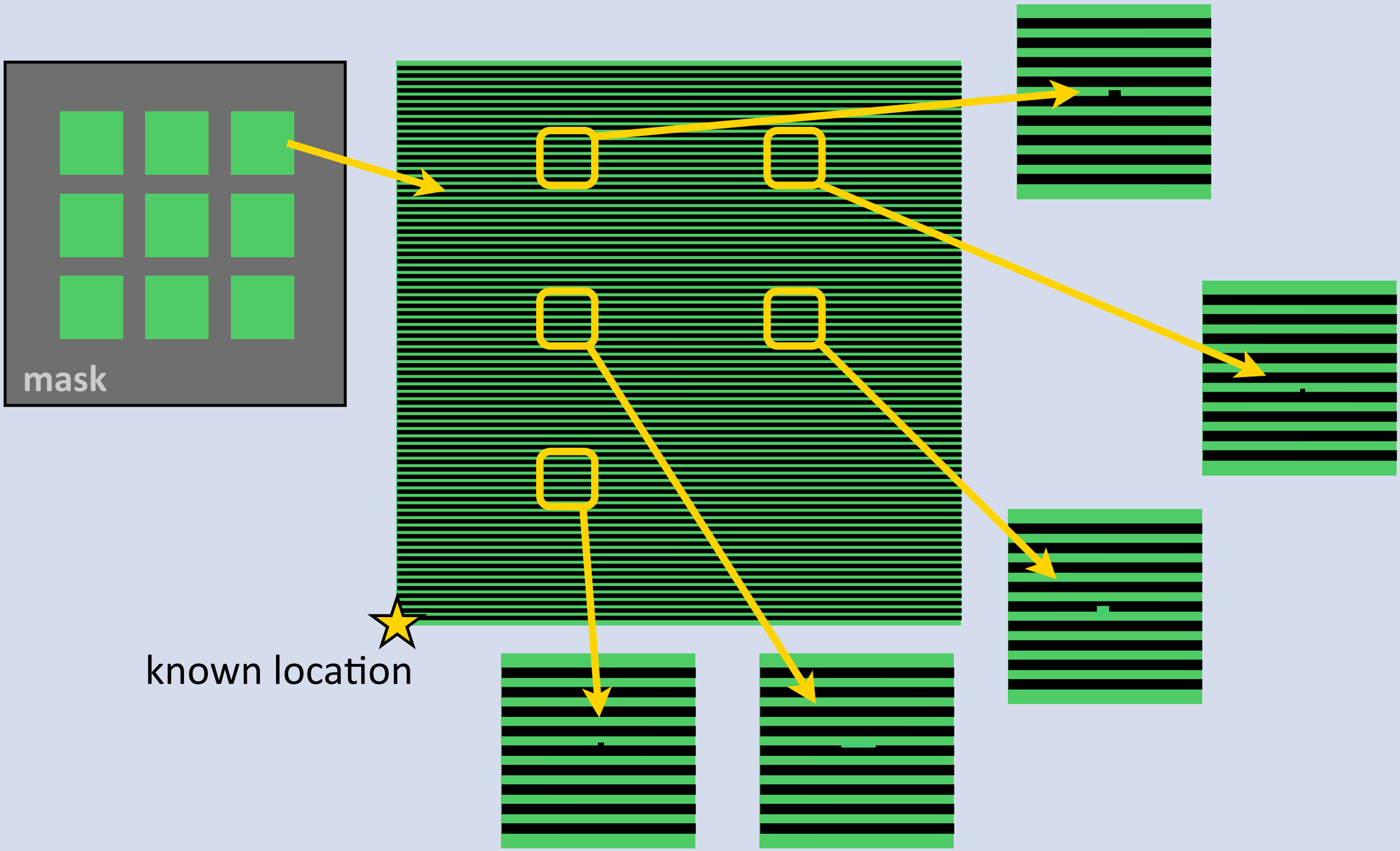
(65.789, 45.587)

(88.291, 70.212)

(98.570, 90.121)

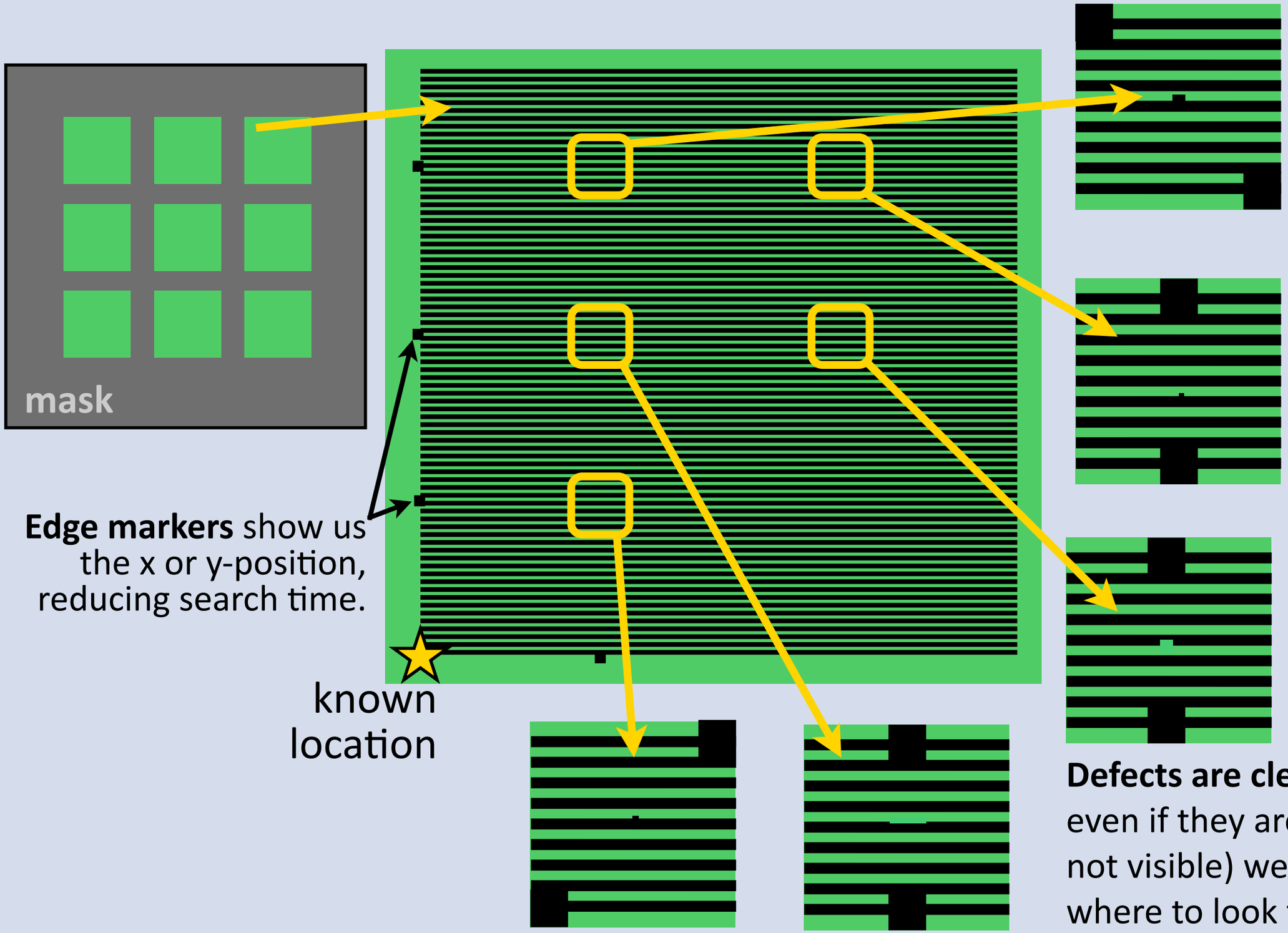
Experiments with Patterned Masks (7)

BAD EXAMPLE #3: ***TINY DEFECTS IN A SEA OF LINES***



Experiments with Patterned Masks (8)

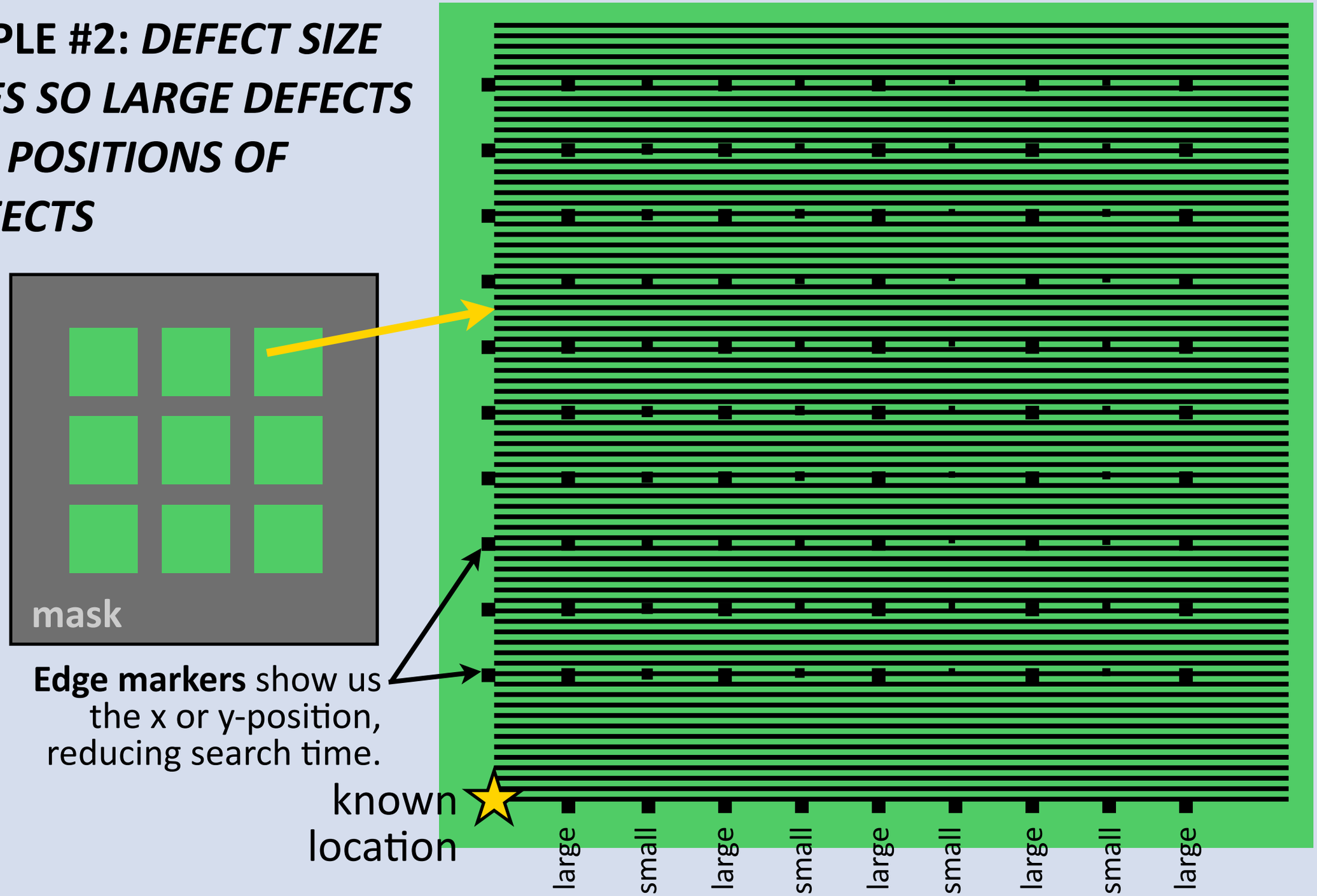
GOOD EXAMPLE #1: *DEFECTS ARE MARKED AND EASY TO FIND*



Defects are clearly marked, so even if they are barely visible (or not visible) we still know exactly where to look for CD changes.

Experiments with Patterned Masks (9)

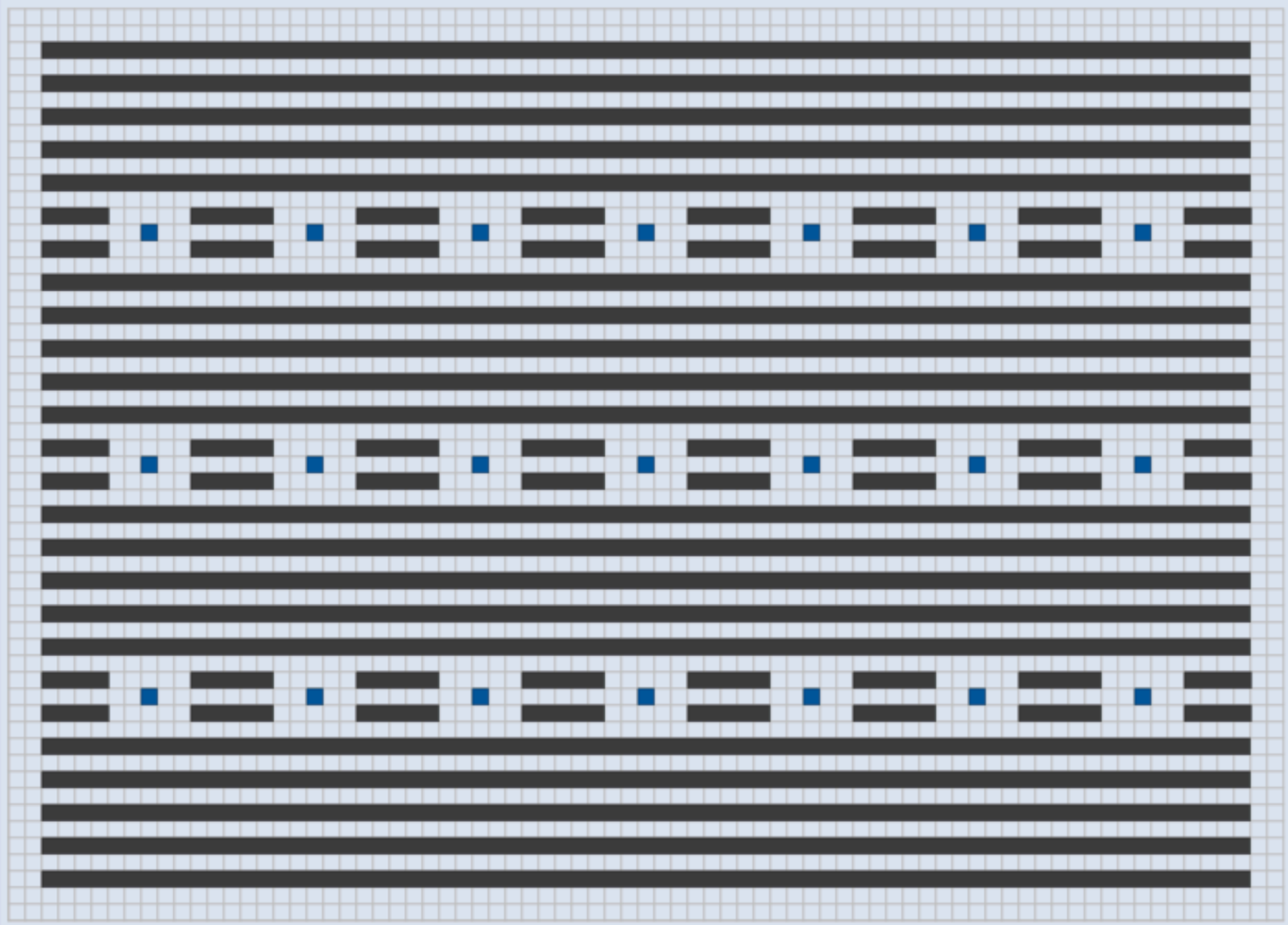
GOOD EXAMPLE #2: ***DEFECT SIZE ALTERNATES SO LARGE DEFECTS SHOW THE POSITIONS OF SMALL DEFECTS***



The defect pattern alternates between large and small defects so we can certainly find the small defect location by looking at positions between large, easy to find, defects with high certainty.

Experiments with Patterned Masks (10)

GOOD EXAMPLE #3:
LINE MEASUREMENTS are improved when we can verify the zoneplate alignment and minimize the aberrations. That can be hard to do with lines alone



Imaging a field of contacts is the most reliable way to perfect the alignment. Contacts can be included in a line pattern (example at right). Here we recommend, contacts > 125 nm wide, with a little extra space around them in the pattern.

The number of lines between the rows of contacts is not important; only that the density of contacts be high enough to have a well spaced array with at least 6x6 to 8x8 contacts within a 30-µm field of view. That is, one contact spaced every 3–5 µm, approximately.

Contact Us

EMAIL IS ALWAYS BEST:

When you contact us, regarding experiment plans and mask shipment, please CC your email to both of us.

KAGoldberg@lbl.gov and **IMochi@lbl.gov**

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