SHARP

Experiment Planning

August 5, 2013

- General information
- Communication of fiducials and measurement locations
- Illumination & imaging properties
- Experiment planning for blank and patterned masks
- Data formats
- EXPERIMENT CHECKLIST

General information on SHARP

The SHARP EUV Microscope is an advanced research prototype, not a commercial system. SHARP began operation in early 2013, and will continue to evolve and improve over time. We welcome your suggestions and ideas, and the opportunity to work with you to get the most from it.

Communication is the foundation of successful user operations and experiments, and this document is intended to provide a common starting point for all experiment preparation. We will periodically update this document to reflect changes and best practices with SHARP.

The latest version of this Experiment Planning document will always be available here

http://sharp.lbl.gov/SHARP_Experiment_Preparation.pdf

When communicating with us, please include the **Mask ID / Name / Serial Number** in every email, PowerPoint, and Defect Location file. We work with a lot of masks.

You're always welcome to contact Ken Goldberg directly at KAGoldberg@lbl.gov.

General information on SHARP

CURRENT SHARP SCHEDULE

http://sharp.lbl.gov/schedule/

CONTACTS

LBNL

Beamline	**1-510-495-2113** (no messages)	
Ken	**1-510-495-2261** (office) 1-510-704-3141 (cell)	**KAGoldberg@lbl.gov** *email is the best way to reach Ken*
Iacopo	1-510-486-6921 (office)	IMochi@lbl.gov
Markus	1-510-486-5680 (office)	MPBenk@lbl.gov

SEMATECH (Project Management)

C.C. Lin	1-518-649-1017 (office) 1-845-392-0128 (cell)	C.C.Lin@sematech.org

We encourage you to please contact us in the early stages of experiment planning, so we can help you get the most out of your data.

General information on SHARP

SHIPPING

To: Kenneth Goldberg
c/o Juanita Jones

1 Cyclotron Road, MS 2R0400
Lawrence Berkeley National Laboratory
Berkeley, CA 94720

1-510-486-4394

Email Tracking Updates: **KAGoldberg@lbl.gov**

- Please ship your mask to arrive *several days before* your shift.
  Internal delays within LBNL can cost us measurement time.
- **Send us the tracking number**. Register us for tracking updates with Mask ID/Name/Serial Number in the *comment* field, for clarity.
- To avoid customs delays, for international shipments please write:
  6-INCH GLASS PLATE. PHOTOMASK. SAMPLE FOR MEASUREMENT.

(Many delays could have been avoided with these six words on the package.)

General information on SHARP

FULL-MASK MEASUREMENT

SHARP's EUV and visible-light microscopes can image *the entire mask surface*.

MASK POSITIONING

We are still evaluating the repeatability of our mask-loading system. It may be on the order of ±100 μm at this time.

Masks are loaded by hand onto a transfer arm. The transfer arm is robotically controlled and places the mask onto a holder.

The mask rests face up on four small Teflon pads, near the corners, and it is held gently from the side with a weak spring force. There is no chuck.

STABILITY

Unlike AIT, SHARP is stable and does not make contact with the front size of the mask at any time.

SPEED / THROUGHPUT

We can unload and load a mask in about 30 minutes. Establishing the new coordinate system could take 15 minutes. When the mask is ready for measurement, we are targeting a rate of about 8 measurement series per hour.

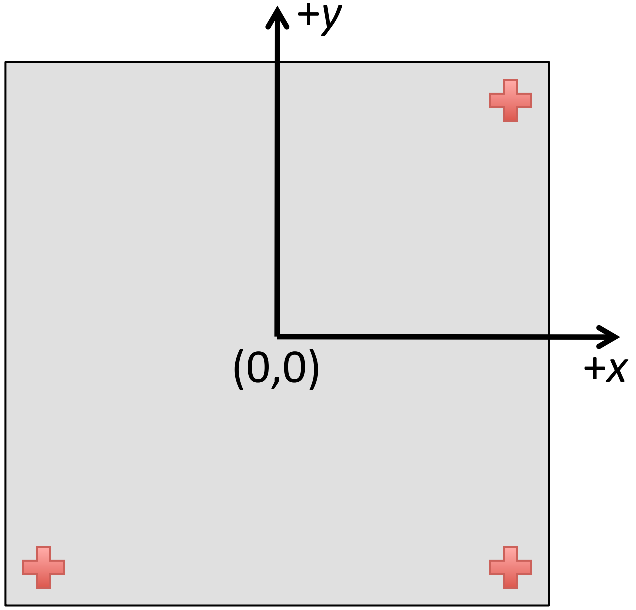
General information on SHARP

COORDINATE SYSTEM

Please help us to remove any uncertainty about the loading direction for the mask. Anything that can help us to identify the +*y* direction by eye will save time.

We rely on known positions and easy-to-identify patterns or markings to properly navigate the mask. We require 3 or more fiducial positions to have good stage positioning accuracy. Each additional fiducial or new measurement point provides additional information to improve the transform, down to µm-scale accuracy.

We prefer a *mm-based*, *center-referenced* coordinate system with +*x* toward the right side of the mask and +*y* toward the top, as you face the multilayer surface.



If you need us to use a different coordinate system, please be as clear as possible with the description. We will work with you to convert it into this format.

If you are referencing coordinates to alignment-crosses please let us know whether the *center* or *edge* of the cross is the reference position.

General information on SHARP

NAVIGATION

Travel. SHARP's *xyz* stages allow us to reach *any point on the mask*, or to move from EUV to the visible-light microscope, in about 30 seconds.

Visible FOV. The visible-light microscope has a 1.4-mm field of view. It can use both bright-field and dark-field illumination to find fiducials and detents. These coordinates can be transferred to the EUV microscope. We are now evaluating the uncertainty and repeatability.

EUV FOV. The standard-NA EUV lenses have a 30-µm-wide field of view. Higher-NA lenses have a somewhat smaller field of view. We can use the EUV lenses to measure fiducial or detent positions. Because of their limited viewing area, they are not efficient for conducting 2D searches.

Marking Defects. For greatest efficiency, isolated defects (on blanks or in dense patterns) should be marked with a nearby detent (10 microns is a good distance), or a pattern marker. As our confidence grows, we may soon be able to find unmarked defects given the (*x, y*) location. But for defects close to the printability threshold, it will always be wisest to mark them in an unambiguous way.

General information on SHARP

IMAGING

The imaging sweet spot it typically several microns diameter. The sweet spot is defined here as the region over which the aberrations are below $\lambda/14$. Lower NA lenses have larger sweet spots. Our goal is always to identify the location of the sweet spot, and to center the measurement point of interest within it.

EXPOSURE TIME

For highest resolution imaging, SHARP exposure times are typically 5 seconds or shorter. If your mask has *low reflectivity*, please let us know in advance, and we can discuss your signal-to-noise requirements.

THROUGH-FOCUS SERIES

We prefer to perform all measurements as part of a through-focus series to ensure that the best-focus position is not missed. So even if you only want *best focus*, we will still take a few z steps to make sure we capture it.

In SHARP, the mask stands still and the zoneplate lens moves through focus.

WAVELENGTH

We can tune the wavelength continuously over a small range near 13.5 nm. SHARP has highest flux between 13.4 and 13.5-nm wavelength.

General information on SHARP

BANDWIDTH

SHARP's EUV bandwidth is narrow to avoid chromatic aberration from the zoneplate lenses. Typical $\Delta\lambda/\lambda$ bandwidth numbers will be 1/1200–1/2000.

CHANGING ILLUMINATION

We can easily switch the illumination settings, in just a few seconds. Side-by-side comparisons of imaging with different illumination conditions can be made.

CHANGING ZONEPLATES

Our stages allow us to switch from one zoneplate to another in just a few seconds. After switching we may spend 2 or 3 minutes refining the alignment and illumination settings, if necessary. Over time, we anticipate that switching times will come down as the zoneplate array alignment becomes well known.

When experiment plans include different zoneplates measuring the same features, we must decide whether to perform all tests with a single zoneplate and then switch, or to switch zoneplates at each location. We will address this on a case-by-case basis.

Available illumination and imaging properties

SHARP has an array of zoneplate lenses for the selection of the NA and the azimuthal angle of incidence for cross-smile studies. In addition, we can customize the illumination to a high degree.

- Note 1: high-NA requires larger central-ray angles. Conventional mask MLs may not support large off-axis angles.
- Note 2: We have noticed problems with some of the high-NA lenses. This is a yield issue. There may be higher aberrations, or non-uniform pupil transmission in the high-NA lenses until we resolve the problem.

For each measurement, please specify {4xNA, azimuth, focal step, and illumination}

4xNA: { **0.25** (6°), **0.33** (6°), **0.35** (6°), **0.42** (8°), **0.50** (8°), **0.625** (10°) }
azimuth: { **–25°**, **–12.5°**, **0°**, **12.5°**, **25°** }
focal step: Typical is 400–800-nm per step. Mask steps are 16x wafer steps.
illumination: { **monopole**, **dipole**, **disk**, **annular**, **quadrupole**, **Quasar 0°** or **45°**, **crosspole 0°, 45°, 90°,** or **135°**}

Note: For each illumination condition, there are up to 3 parameters that must be specified.

Communication of Fiducials and measurement locations

DATA FORMATS

At present, we prefer to use **Excel** or **CSV** (text) format for communicating measurement positions and illumination conditions to the control software.

An example of the file format is given below. The definitions for the illumination are given at this link.

Please see **http://sharp.lbl.gov/plans/** for instructions.

Note that all (*x, y*) values are **mm**; all positions are **relative to center**.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	# SHARP EUV Microscope Experiment Plan Demo File															
2	# Friday August 5															
3	# Radiation hardness tests															
4	# Defects created by Bosch chromium inversion reaction															
5	#															
6	id	plan	x	y	na	illum	arg0	arg1	arg2	azimuth	dz	nsteps	comment	other	data	ok
7	F1	1	-65.0000	-65.0000	0.33	2	0.70	0.1	45.0	0.0	0.4	15	Fiducial LL	#	#	#
8	F2	2	-65.0000	65.0000	0.33	2	0.70	0.1	45.0	0.0	0.4	15	Fiducial UL	#	#	#
9	F3	3	65.0000	-65.0000	0.33	2	0.70	0.1	45.0	0.0	0.4	15	Fiducial LR	#	#	#
10	F4	4	65.0000	65.0000	0.33	2	0.70	0.1	45.0	0.0	0.4	15	Fiducial UR	#	#	#
11	# there are six measurement points that we measure twice															
12	12	5	-11.8460	43.6080	0.25	2	0.70	0.1	45.0	12.5	0.4	17	Debye-Waller coating	0.103	0.632	aquilonia
13	25a	6	44.3090	-47.3910	0.25	2	0.70	0.1	45.0	12.5	0.4	17	Debye-Waller coating	0.944	-0.554	cunicularia
14	25b	11	-49.7460	4.3410	0.25	2	0.70	0.1	45.0	12.5	0.4	17	acicular repair	-0.852	-0.765	exsecta
15	87	12	-3.3110	-54.6220	0.25	2	0.70	0.1	45.0	12.5	0.4	17	acicular repair	0.124	0.408	fusca
16	64	17	-70.2940	-65.8150	0.25	2	0.70	0.1	45.0	12.5	0.4	17	terbium nitride capping layer	0.370	0.563	lemani
17	77	18	26.1310	32.0790	0.25	2	0.70	0.1	45.0	12.5	0.4	17	terbium nitride capping layer	-0.112	-0.915	lugubris
18	# repeat the six points with different NA and illumination settings															
19	12	19	-11.8460	43.6080	0.33	3	0.81	0.2	12	0.0	0.4	17	Debye-Waller coating	0.103	0.632	aquilonia
20	25a	20	44.3090	-47.3910	0.33	3	0.81	0.2	12	0.0	0.4	17	Debye-Waller coating	0.944	-0.554	cunicularia
21	25b	21	-49.7460	4.3410	0.33	3	0.81	0.2	12	0.0	0.4	17	acicular repair	-0.852	-0.765	exsecta
22	87	22	-3.3110	-54.6220	0.33	3	0.81	0.2	12	0.0	0.4	17	acicular repair	0.124	0.408	fusca
23	64	23	-70.2940	-65.8150	0.33	3	0.81	0.2	12	0.0	0.4	17	terbium nitride capping layer	0.370	0.563	lemani
24	77	24	26.1310	32.0790	0.33	3	0.81	0.2	12	0.0	0.4	17	terbium nitride capping layer	-0.112	-0.915	lugubris

An example plan file, in Excel format.

Experiment planning for blank and patterned masks

BLANK MASKS

Small, isolated blank-mask defects without nearby markers are very difficult to find and measure. Small defects only show up in focus, and it can be difficult to determine best focus on a low-roughness blank.

A detent or small pattern nearby allows us to determine focus and *xy* position with certainty.

Blank masks need some kind of fiducial strategy (with detents, crosses, or other markers) that defines the coordinate system for navigation. Having a good coordinate system, SHARP will be able to navigate to arbitrary defects to within a few microns.

PATTERNED MASKS

For obvious reasons, patterned masks are usually significantly easier to measure than blanks. Still, because the EUV field of view is small, it is important to have ways to remove ambiguity or uncertainty—especially in large repeating patterns.

(continued…)

Experiment planning for blank and patterned masks

PATTERNED MASKS *(cont'd)*

Communication of pattern features, and key locations helps us to operate the tool efficiently and navigate quickly. The best way to provide this is in a **PowerPoint** or **PDF** file, with images and screen-shots of GDS (or equivalent) showing how to navigate to the points of interest. For that purpose a multi-step 'zoom-in' can be helpful.

Labels and symbols with unique features are welcome in any mask pattern design to ensure easier navigation and measurement success.

Borders, Edges, and Corners of large patterns can be used as easy-to-find, improvised fiducials, provided that their (*x*, *y*) locations are given in advance as part of the experiment plan. It is helpful to know the widths of spaces and gaps in the pattern. *If a large pattern is repeated, please let us know the x and y pitch.*

SHARP's In-Situ Visible-Light Microscope can be used to assist navigation.

Aberration minimization is a constant concern. We always try to place the point of interest in the imaging sweet spot. Some patterns (especially loose-pitch, darkfield contact arrays or almost any small-scale, 2D, darkfield pattern) help us to refine our alignment because they provide excellent feedback on the spatial variation in the imaging. If possible, with programmed-defect masks, include patterns for alignment.

Data formats

IMAGE DATA

We will provide the image data in **16-bit, grayscale PNG file format**. This is a lossless data format that is widely readable. If another data format is desired (e.g. 16-bit TIFF, 16-bit BMP) please let us know. Be aware that 8-bit file formats (grayscale JPEG, 8-bit BMP, etc.) are only appropriate for thumbnails, not for processing or analysis.

Link. Please see **http://sharp.lbl.gov/userdata/** for the latest information.

File names. The file names will include the mask name, the data, a series number, and an image number, making them unique. The presence of the series number makes the files easier to sort and refer to, within each day's data.

Metadata. We are working on a simple/secure web interface for creating the Excel-readable CSV files that contain the image metadata. Until that is ready, we will bundle the metadata file with the images.

Data formats

Data Volume. At full speed, SHARP could generate up to 8 GB of raw data per shift. We are considering ways to reduce this data load. One idea is to record one full-field image per series (for reference), but cut down the output size of the other images by recording only the sweet spot and the region out to 15-µm width. This could reduce the data volume by ~4x, and could be a user preference.

DATA TRANSFER

With AIT, image data was available on shipped DVD-ROM or USB thumbdrive, or it could be made available for download with secure FTP (SFTP). We can accommodate users requests in this regard. Please let us know what you prefer.

If there is a high demand, we may work toward providing an http web-browser interface to securely download a zipped archive of a large number of image files.

Feedback

YOUR FEEDBACK HELPS SHARP TO IMPROVE

For SHARP to realize its potential, we need constructive input from users. Please let us know how SHARP could better serve you. For example, we especially welcome feedback (good or bad) on the following topics.

- Communication for experiment planning and the conveying of results
- Data formats and information
- Illumination settings (partial coherence)
- Uniformity requirements
- Tool features

USER OPERATORS, *in the future*

We are designing SHARP to be relatively easy to operate, like a sophisticated SEM. Many synchrotron beamlines train users to become qualified tool operators. In time, it should be possible to train MC or SEMATECH users to become proficient at safe operation and data collection with SHARP as well. Please let us know if you have staff who are interested in becoming SHARP user/operators. We anticipate that the first few months of operation will see significant expansion of automation, control, and efficiency as SHARP becomes more user-friendly and our team learns the tool.

EXPERIMENT CHECKLIST

MASK PACKAGING

- Standard mask loading orientation is with *+y toward the hinge*. If your mask deviates from this, please make it clear to us how the mask is intended to be oriented, and how it is loaded in the box.

SHIPPING

- Ship your mask to arrive ***several days in advance*** of your shift.
- Send email tracking information to Ken, KAGoldberg@lbl.gov.
- International shipments: write **"6-inch Glass Plate. Sample for Measurement."**

EXPERIMENT PLAN

- Consult with LBNL early in your experiment planning, wherever possible.
- Tell us whom to contact as the *point person* within your organization (email and phone numbers).
- On the day of the experiments, make sure the point person is available to answer questions, should they arise. Especially in the morning.
- Using an experiement plan file, please tell us the **NA**, **azimuth**, **through-focus step size**, and **illumination conditions** for each set of measurements. Also, please indicate a priority (or ordering) for the data collection.

FINAL NOTE

THE IMPORTANCE OF PUBLICATION

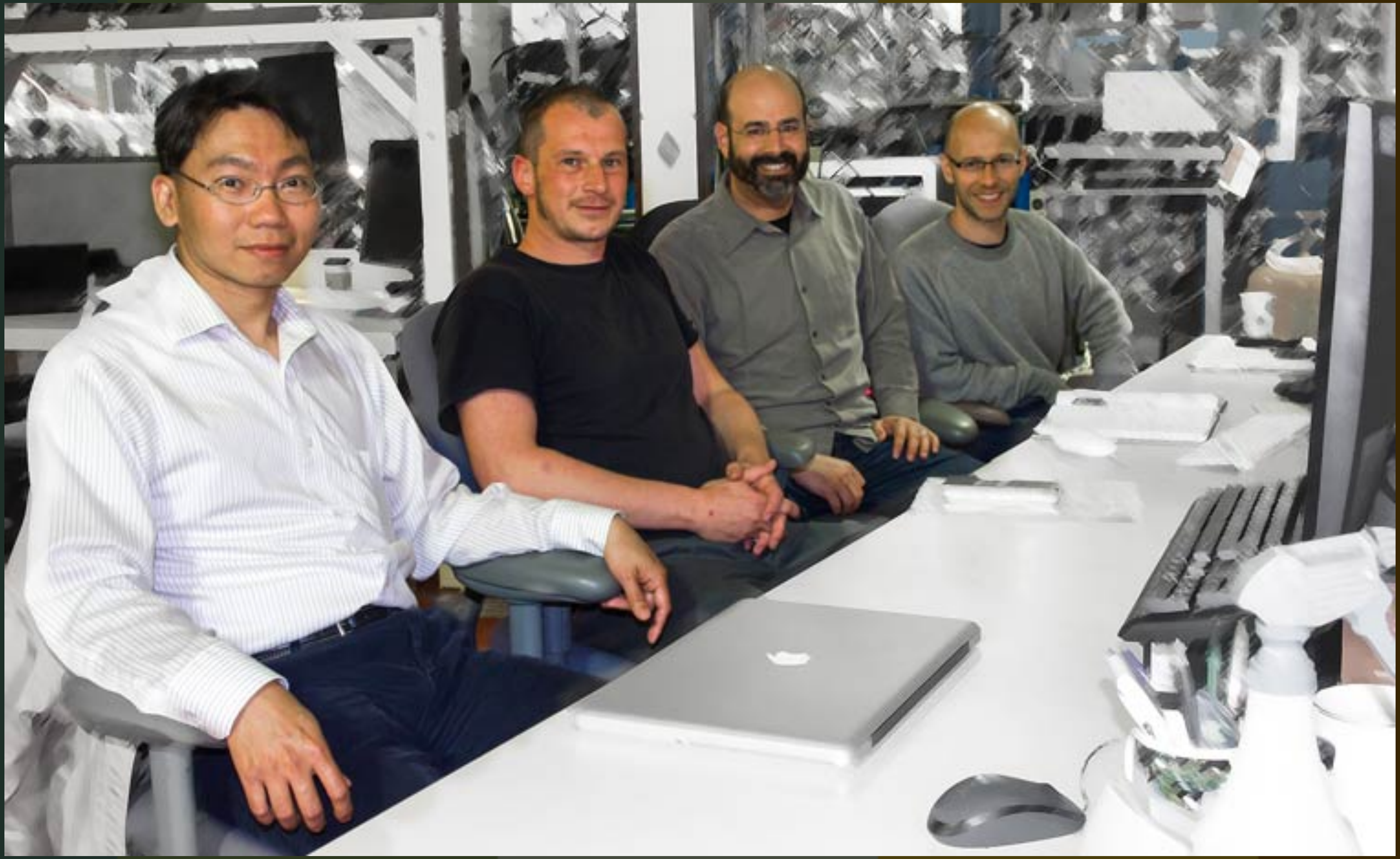
At the National Laboratory, our performance is evaluated based on the number of publications we author and co-author. In many ways, it is the only metric that the Department of Energy and our lab management use to determine if a project is performing at a high level, worthy of their continued support. Our personal evaluations are also closely tied to our publication rate.

We appreciate the opportunity to participate in this research with you, every day. Because of the unique nature of our tools and expertise, we hope that you view our contributions to your experiments as more than a routine service. *Where appropriate, we ask that you include us as co-authors on the research papers generated from SHARP data.*

We respect the business-sensitive nature of our collaborative work, and we take steps to protect your individual plans and data. We also recognize that SHARP provides a great value to the whole EUVL community when its results can be published and shared. Wherever you deem appropriate, we would like to work with you to find key results that deserve wider recognition, and to publish those results with you.

SHARP

Acceptance Tests—May 16, 2013



C.C. Lin, Markus Benk, Kenneth Goldberg, Iacopo Mochi
C.C.Lin@sematech.org • MPBenk@lbl.gov • KAGoldberg@lbl.gov • IMochi@lbl.gov

We are looking forward to working with you on SHARP!