Metrology Test Artifact Availability Improvement

Benjamin Bunday
AMAG Consulting, Schenectady, NY, 12303, USA

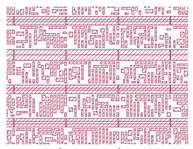
SPIE Advanced Lithography 2022
April 27, 2022, San Jose, CA
SPIE Publication #12053-70

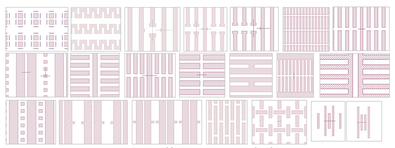
BACKGROUND

- A common issue among metrology R&D community is low availability of mission-critical test samples/artifacts.
- Challenging and/or diagnostic samples representing leading edge of key technologies are crucial for equipment/application development, for evaluating, monitoring & calibrating equipment, and for collaborating with other entities. Access to such samples also determines which experiments are possible and what can be published externally versus internally.
- However, availability of such samples usually is quite limited as customers' product is usually tightly controlled, restricted intellectual property (IP).
- Difficulties in availability of important metrology test artifacts is being addressed with a new advanced metrology patterning reticle, AMAG7, which makes available again and updates the suite of key metrology diagnostic and experimental content to the industry previously provided by SEMATECH AMAG.
- This poster will introduce the newly-designed AMAG7 pattern and demonstrate the achievable lithography and possible test artifacts that can be enabled.

AMAG7 RETICLE OVERVIEW

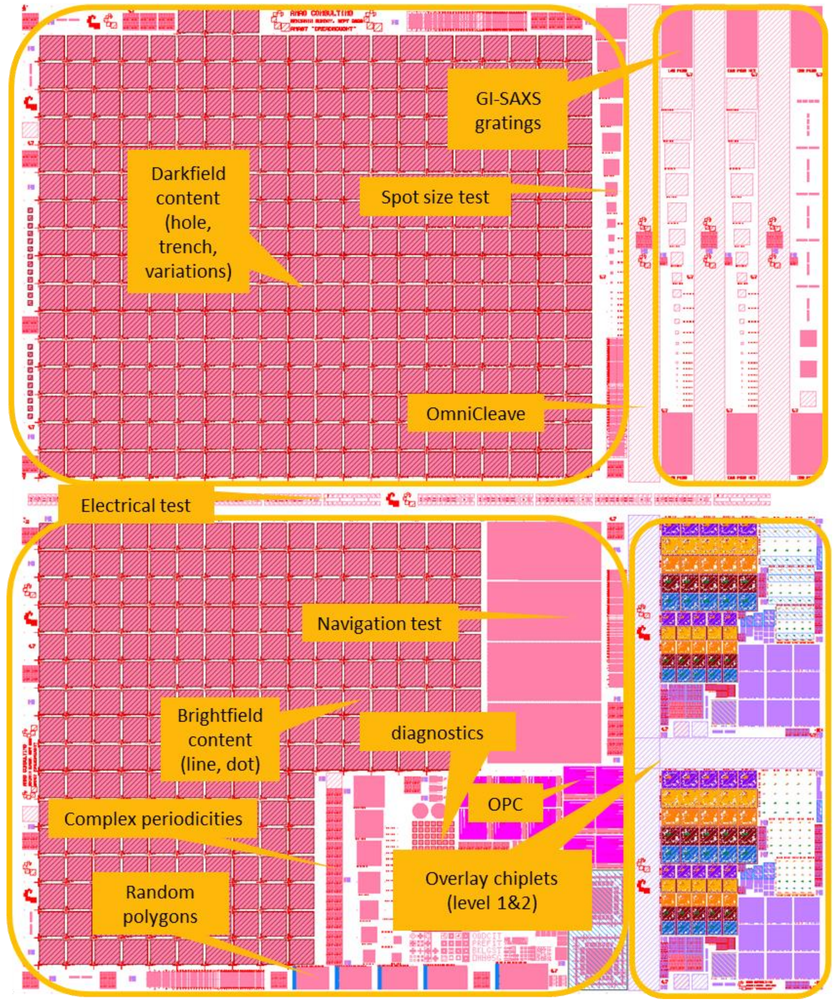
- AMAG7 is the culmination of the evolution of SEMATECH AMAG's well-known flexible set of reticles for metrology-centric test wafers, combining the best features from SEMATECH's AMAG4, AMAG5 and AMAG6 but updated to present needs with new content to address new use cases since AMAG6.
- AMAG7 includes updated and improved elements, useful as a very versatile patterning platform for short-loop metrology test wafers for many applications, addressing many new use cases which have evolved recently (contours, EPE, two-level structures and more), with a pattern set that is very thorough and wide ranging in nominal sizes, spanning between iArF lower resolution limits with 1:1 dense features up through 1um CD and 9:1 isolated pitches including very large gratings of line, trench, hole & dot arrays in many sizes with holes in both square and hexagonal arrays. With these, practically any 1-level short-loop target within applicable dimensions is enabled, given the necessary prerequisite processing capabilities.
  - 547x 0.8mm large line/space and hole and dot gratings measurable by any tool type, from resolution limit up to 1um feature sizes in many steps, covering most design rules achievable by iArF lithography.
  - Tool characterization, optimization, development, calibration, monitoring, round-robin comparisons.
  - Precision, accuracy, matching, navigation, pattern recognition.
  - OPC & DOE of pitchwalk & 2D random polygon fields for contour/EPE/D2D testing, gratings with intentional roughness & added variation, 2-level overlay for FinFET or VIT, variable film pad sizes, e-test module, cleavables, etc.
  - overlay module with two levels; onboard those chips are more large gratings allowing for two level dual damascene or FinFET gratings, among other form factors.
- AMAG7 is measurable by any metrology including CD-SAXS, OCD, any imaging metrologies such as CD-SEM/AFM, large FOV SEM, HV-SEM, etc, allowing collaboration & correlation studies among any CD metro tools of any vendors or across the industry.


Random polygons


Full OPC module


2-Level Gratings

AMAG7 FLOORPLAN



AMAG TEST WAFER FOUNDRY

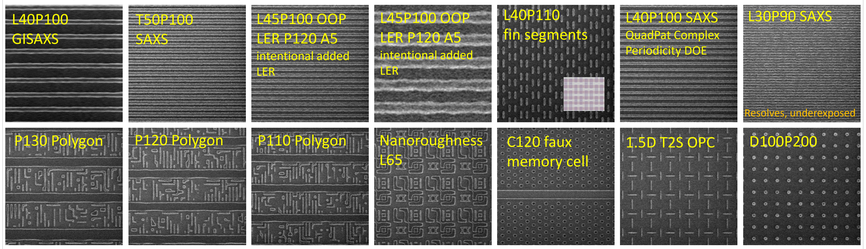
- AMAG Consulting has revived & improved upon the SEMATECH AMAG tradition of providing the industry a source for leading edge, thorough and easy to use IP-neutral metrology test samples. Metrology-centric test wafers built with AMAG7 and patterned into various materials & applications are now available for order for various applications for the development and tool supplier community, and new products leveraging the AMAG7 pattern can be developed to meet specific needs.
- Intellectual property (IP) embodied within AMAG7 designs and AMAG7 printed wafers is owned and copyrighted ©2020 by AMAG Consulting, LLC. AMAG7 printed wafers allow IP-flexible options for using data/results.
- Reticle usable with many processes at various foundries allowing for many different products with very flexible form factor. Flexible design means reticle should stay pertinent for many years as with past AMAG reticles.
  - HAR etched features
  - 1-layer oxide, a-Si, poly or metal etched features
  - CMP metals
  - FinFETs, damascene trench or VIT
  - 2-layer structures with overlay DOE
  - Conformal films over topography
  - Spacer DP, ONO, and more.

GENERAL INITIAL LITHOGRAPHY PERFORMANCE

- Initial lithography developed for general hole & line/space conditions, and first test wafers are coming available in a few simple stacks with more to come as processes adapted to AMAG7 pattern.

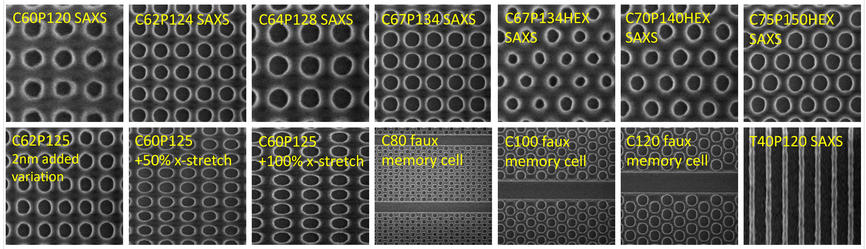
AMAG7 Line/space condition

- Line/space target: Most line/space content prints down to 100nm pitch at L40P100 condition. 2D shapes better at 120nm pitch. Holes 100nm and above also pattern on same wafer.



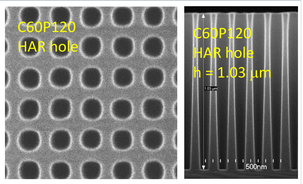
AMAG7 Contact hole condition

- Hole target: Most square array hole content prints down to 120nm pitch. Hex hole content patterns fine at C70P140HEX. Trenches of 120nm pitch are also patterned successfully on same wafer.



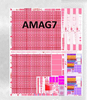
CONCLUSIONS

- AMAG7 advanced metrology test reticle is available for a few initial stacks including 1um & 1.5um deep HAR holes and line/space/hole in 70-100nm oxide, and more stacks will get adapted to the new pattern as needed.
- AMAG Consulting acknowledges and thanks NY Creates fabrication facility for their efforts in achieving the initial lithography, and Benchmark Technologies for reticle fabrication.



ABOUT AMAG CONSULTING, LLC

Available via AMAG Consulting



- Test artifact foundry with AMAG7 reticle
- SEM simulation with AMAG SimuSEM software
- Semiconductor metrology expertise
- Updated industry-wide application-level metrology use-case & gaps analysis
- Specifications & samples usable/adaptable for equipment supplier enablement
- BKM's such as precision, accuracy & matching improvement
- Training in general metrology topics
- Very broad network of contacts

About AMAG

- SEMATECH AMAG (Advanced Metrology Advisory Group) for 20 years was very influential in guiding semiconductor metrology to keep pace with the ITRS roadmap
- Strong collaboration among IC manufacturers, equipment suppliers, laboratories & universities identified critical industry metrology problems and formulated/executed consensus solutions
- AMAG Consulting's Benjamin Bunday was AMAG Chair from 2001-2015, and led the team that developed such AMAG items and can still leverage products of those efforts
- AMAG Consulting offers similar enablement activities in the SEMATECH AMAG tradition

Goal of AMAG Consulting

- **Leverage AMAG tradition to enable metrology sector progress.**

Benjamin Bunday (cell) +1 (512) 627-7391 (work) +1 (512) 627-7391 benbunday@amag-consulting.com https://amag-consultingllc.com

AMAG SimuSEM

+1 (512) 627-7391
amag-consultingllc.com

AMAG SimuSEM—SEM simulation software

•AMAG SimuSEM is a software package for simulating scanning electron microscope images (SEM images) and electron interactions with solids. The core of the simulation code is NIST's JMONSEL source code, with many improvements and utilities added to it, along with full 3D visualization thru building all JMONSEL routines directly into a 3D Blender interface.

•Effectively, AMAG SimuSEM realizes the true completion of much of the original vision for JMONSEL, and updates the software to current standards by greatly improving utility, productivity, flexibility, visualization, accessibility, and achievable complexity of designed features while improving simulation speed and allowing user to run on remote resources at larger scale. It makes JMONSEL a software solution for SEM simulation and electron beam interactions with solids much more useful for many more simulation possibilities and efforts.

•Additionally, AMAG SimuSEM has been built to operate in a virtual machine (VM) environment through a web portal, meaning all the heavy calculation capacity needed can be in VMs at external servers and runs split among multiple VMs for speed, or on corporate intranet accelerating performance while leaving user's PC free for other work, or can be run multithreaded on any recent generation PC.

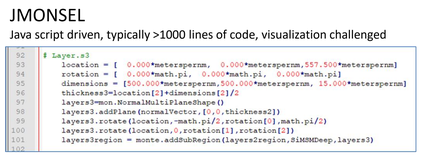
NIST's JMONSEL

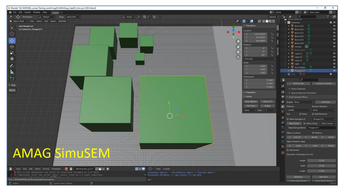
•JMONSEL, Java MONte Carlo Simulator for Secondary Electrons, is a 3D electron beam simulation software package developed and programmed in the 2010-12 timeframe at National Institute of Standards & Technology (NIST) by Dr. John Villarrubia using Java/JYTHON, funded by SEMATECH AMAG to enable limits simulation studies for defect & critical dimension SEM metrology.

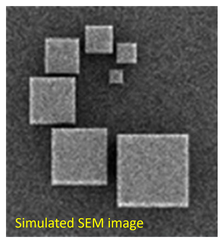
•JMONSEL uses finite element analysis (FEA) to track primary electrons as they enter a material, scatter, lose energy, and generate secondary & backscattered electrons. By monitoring the electrons that exit the material and are captured by a detector (software counter element), the electron yields can be found at any point designated as a target pixel. The physical models in JMONSEL are the best-known models in the literature in the energy ranges used here, open-source, with complete transparency in their documentation, definition, implementation and execution, as programmed by NIST, with a decade of validation data and wide acceptance by the industry.

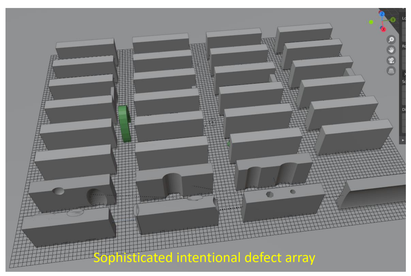
•Adding the GUI and other improvements to the venerable JMONSEL code, AMAG SimuSEM is the user-friendly version of JMONSEL with rich & reliable visualization, with the scripting handled automatically, allowing the user to transparently unlock this powerful code through the greatly improved interface. With the script rigor removed, JMONSEL, thru AMAG SimuSEM, is now capable to address many more simulation cases with more complexity than in the past.

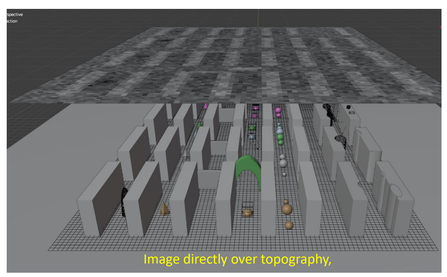
JMONSEL
Java script driven, typically >1000 lines of code, visualization challenged

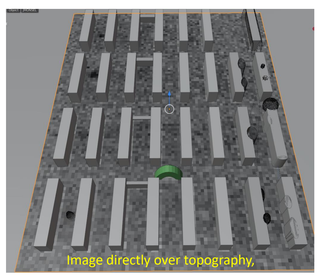












AMAG SimuSEM GUI

•3D Blender interface allows scaling, moving & rotating primitive and user-defined shape objects & Boolean operators for sample design with outstanding visualization.

•Discretely-defined height map objects for rough features and edges.

•Moderate but growing materials database with path to growth.

•Adjustable beam energies, beam spot sizes and tilt beam, user-defined discrete detectors with tunable energy windows, and other SEM variants possible.

•User can see results image for SE, BSE or user-defined energy windows.

•Energy, angle & detector hit histograms and maps. Energy absorption maps.

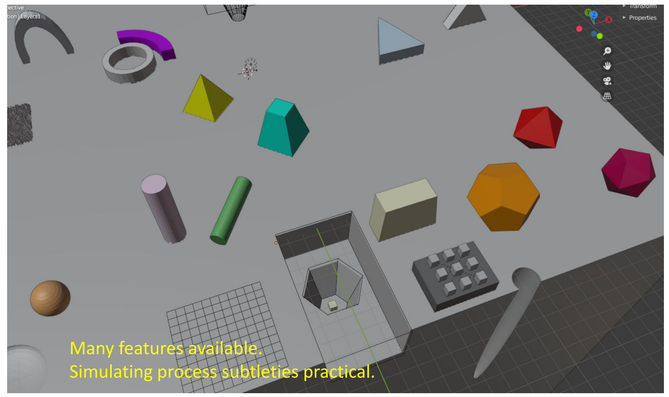
•Fully viewable electron trajectories in 2D & 3D.

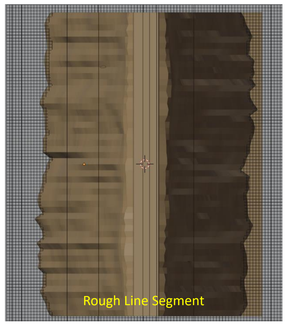
•SimuSEM runs simulation in background, with results loaded back to SimuSEM for analysis and detailed viewing in the rich Blender graphics environment.

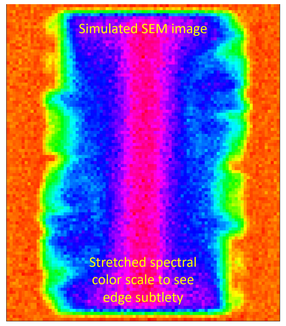
•AMAG SimuSEM's GUI removes the steep JMONSEL learning curve and replaces it with an elegant, intuitive, modern way to use all of JMONSEL's features, plus many improvements. The code is evolving with charging and defined roughness, new materials, and more.

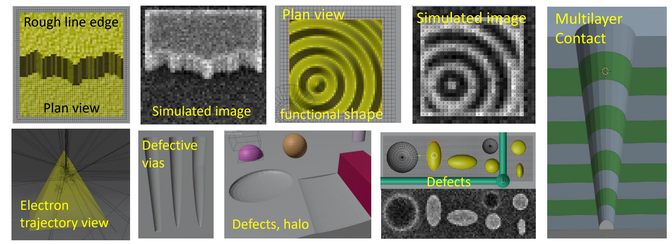
•SimuSEM is very flexible, capable of valuable simulation support for many widesoread metrology community needs:

- •Model Based Metrology development
- •Hybrid metrology comparisons involving SEM
- •HV-SEM/OVL exploration
- •SEM imaging condition optimization
- •Limits, Gaps Analysis & Feasibility studies
- •Faux image generation for AI training
- •Calibration of analytical models
- •Fundamental understanding of signal generation in tough cases



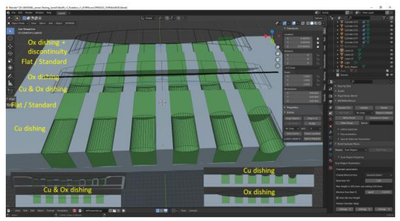






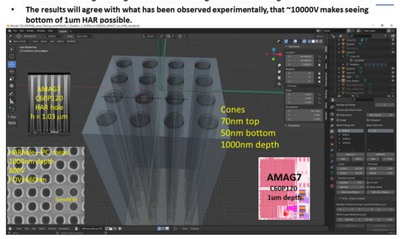
Cu CMP dishing

- Modeled grating-wide oxide dishing both with & without Cu dishing
- Also flat control features to compare signals



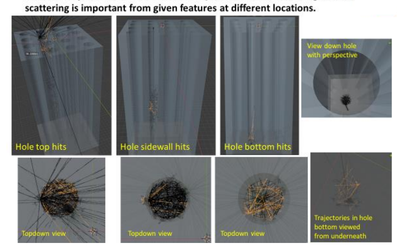
AMAG SimuSEM & AMAG7 HAR holes

- AMAG SimuSEM used to study measurements of 1um deep AMAG7 HARholes.
- DOE of beam energies along hole radius to seek signal from known edge at hole bottom.
- The results will agree with what has been observed experimentally, that ~10000V makes seeing bottom of 1um HAR possible.



HAR hole signal (1 um depth)

- Views of trajectories can be viewed for qualitative understanding of what scattering is important from given features at different locations.



Benjamin Bunday (cell) +1 (512) 627-7391 (work) +1 (512) 627-7391 benbunday@amag-consulting.com https://amag-consultingllc.com