Metrology test artifact availability improvement

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ABSTRACT

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. New content covers a broad range of scale regimes from the absolute resolution limits of iArF lithography up to 1um for comparing to larger scales, and including new use cases which have evolved since previous AMAG reticles such as features for contour metrology, EPE, two-level gratings and more. The main grating content of lines, trenches, holes, dots and many variations thereof, is in form of 547 huge 0.8mm gratings measurable by any type of CD measurement tool in discussion in the metrology sector including CD-SAXS with large spot sizes but also by any other tool type with smaller sampling areas, resulting in new IP-neutral test vehicles to enable full open collaboration across the industry. This poster will introduce the newly-designed AMAG7 pattern and demonstrate the achievable lithography and possible test artifacts that can be enabled.

Keywords: AMAG, test wafer, artifact, CD-SEM, OCD, AFM, SAXS, reticle, contour

INTRODUCTION

For many years, a common issue among metrology tool suppliers and other metrology sector researchers and developers has been a drought in availability of mission-critical test samples and artifacts for their work. Challenging and/or diagnostic samples representing the leading edge of key technologies are crucial for equipment and application development, for evaluating, monitoring and calibrating equipment, and for collaborating with other entities such as existing or potential customers or other tool supplier partners. 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 product from their customers is usually tightly controlled intellectual property (IP), which means much work is blocked by sample availability or is restricted to only private parties to protect any IP.

Before SEMATECH ceased operations, SEMATECH AMAG used to provide such samples in this area to many collaborators for CD, overlay, films and defect metrology equipment suppliers, and allowed a limited license to publish data and results from such wafers. However, since then, such sample opportunities are difficult to attain. AMAG Consulting, with the mission of enabling sector progress, has begun an effort to make such mission-critical samples more widely available again, basically starting where SEMATECH AMAG left off. A new iArF lithographic reticle has been designed, built and demonstrated for challenging and applicable advanced metrology, AMAG7.

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; while those reticles were dated [1][2][3][4][5], the model of their content and use case brought to current standards is needed by the industry as an IP-neutral vehicle to get test wafers for collaborative work. All legacy content is updated and applied to the latest iArF lithography and collected into one reticle field. The main CD content is 547 huge 800 um gratings of hole, dot, line, trench and many other interesting features, ranging from iArF resolution limits up to a full micron so all scale ranges are present for thorough metrology work, in a form factor measurable by any CD metrology tool including any vendor's CD-SAXS, and including a few GI-SAXS targets. These features allow full collaboration or round-robin studies among any CD metrology suppliers. AMAG7 also includes large fields of random polygon patterns which are intended for testing large FOV SEMs, die-to-database testing, or contour metrology. A typical OPC module is included for allowing such contour OPC data to be collected. Navigation test patterns, pattern recognition tests, and many more tool diagnostic features are also included. A full-factorial DOE of OCD gratings with intentional complex periodicities to serve as mandrels allows studies of octa-patterning pitch complexities and also makes an excellent EPE evaluation target set. Some of the gratings

were designed to be experiments, including intentional shifts, errors, intentional roughness or hole-to-hole variation, and dual hole size populations to mimic dual patterning and allowing for histogram studies of large numbers of holes. Holes on AMAG7 come in both square and hexagonal arrays, and gratings of faux VNAND are enabled to allow exploration of ONO HAR VNAND metrology. AMAG7 also includes an overlay module with two levels, and onboard those chips are more large gratings allowing for two level dual damascene or finFET gratings, among other form factors.

This poster will show details about AMAG7's design, and also show the achievable lithography and possible applications. It is hoped that this new industry resource will greatly improve accessibility to key sample needs in our sector and that this will help drive future collaboration and sector progress.

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, using the same strategy and mission as with the previous SEMATECH AMAG reticles in combining the best features from AMAG4, AMAG5 and AMAG6 but updated to present needs with new content to address new use cases since AMAG6. These enable challenging & diagnostic metrology test samples to be built at the limits of immersion iArF lithography. AMAG7 can do anything the previous AMAG reticles could do, but thoroughly updated and much better as AMAG7 addresses many new use cases which have evolved since AMAG6 was designed over a decade ago, with a pattern set that is much more thorough and wide ranging in nominal sizes, spanning the limits between iArF lower resolution limits with dense features and up thru 1um CD and isolated (9:1) pitches.

AMAG7 includes many artifacts for metrology tool characterization and maintenance, as well as a very broad general set of very large gratings of line, trench, hole & dot arrays in many sizes from 30nm to 1um and pitches from 1:1 dense to 9:1 iso capable of measurement by any metrology tool with up to 1mm spot size, and including special applications and variations. With these, practically any one-level short-loop target within applicable dimensions is enabled, given the necessary prerequisite processing capabilities. AMAG7's grating set, consisting of 547 800 μm padsize gratings, is measurable by any metrology including CD-SAXS, OCD, and any imaging metrologies such as CD-SEM/AFM, large FOV SEM, HV-SEM, etc, allowing correlation studies among any CD metro tools of any vendors. And all content is designed with metrology-friendly pattern recognition for improved utility over other options. This large grating module consists of, more specifically:

- Line/space (24 different CD, 6 pitch ratios from 1:1 dense to 9:1 iso up to 120nm CD, 1:1 dense only for 150nm CD and above)
- Trench (20 different CD, 6 pitch ratios from 1:1 dense to 9:1 iso up to 120nm CD, dense only for 150nm CD and above)
- Dot (16 different CD, 3 pitch ratios from 1:1 dense to 3:1 semi-iso, plus a HEX grating for each CD)
- Hole (16 different CD, 6 pitch ratios from 1:1 dense to 9:1 iso, plus two pitches of HEX for each CD)
- Specialty applications including FinFET and 3D memory architectures, elliptical holes, superlattices, etc.
- Variations on key features including intentional feature-to-feature variation, intentional roughness, intentional shifts
- 10 of the gratings are 2-level onboard the overlay chiplet, including trench/via damascene, finFET device and cross-hatched line gratings, double-patterned contact holes, hole-on-gate, misaligned 2 levels of parallel lines, etc.

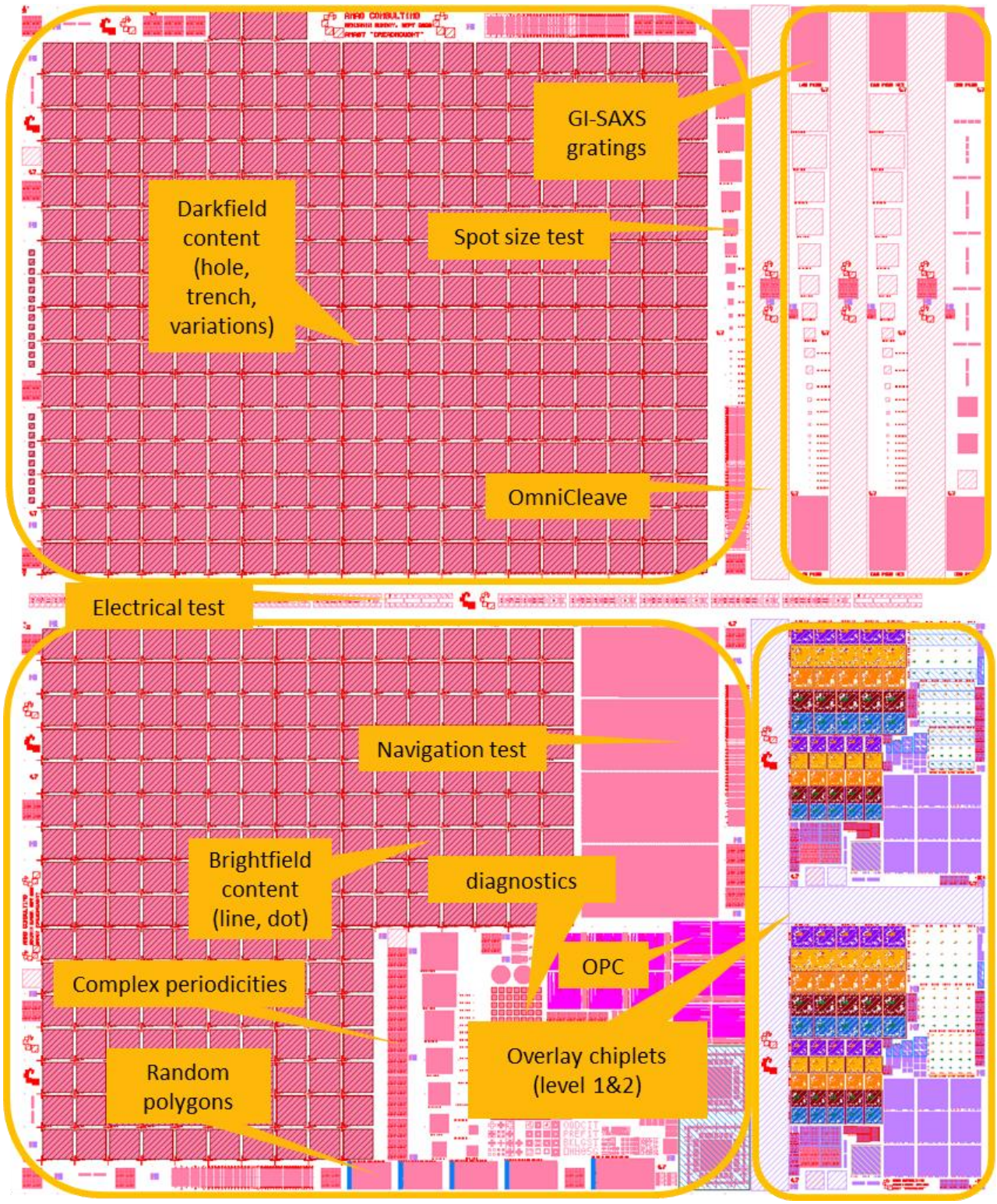

Figure 1. AMAG7 floorplan, marking some of its key features. Reticle is full standard 26 x 32 mm field size.

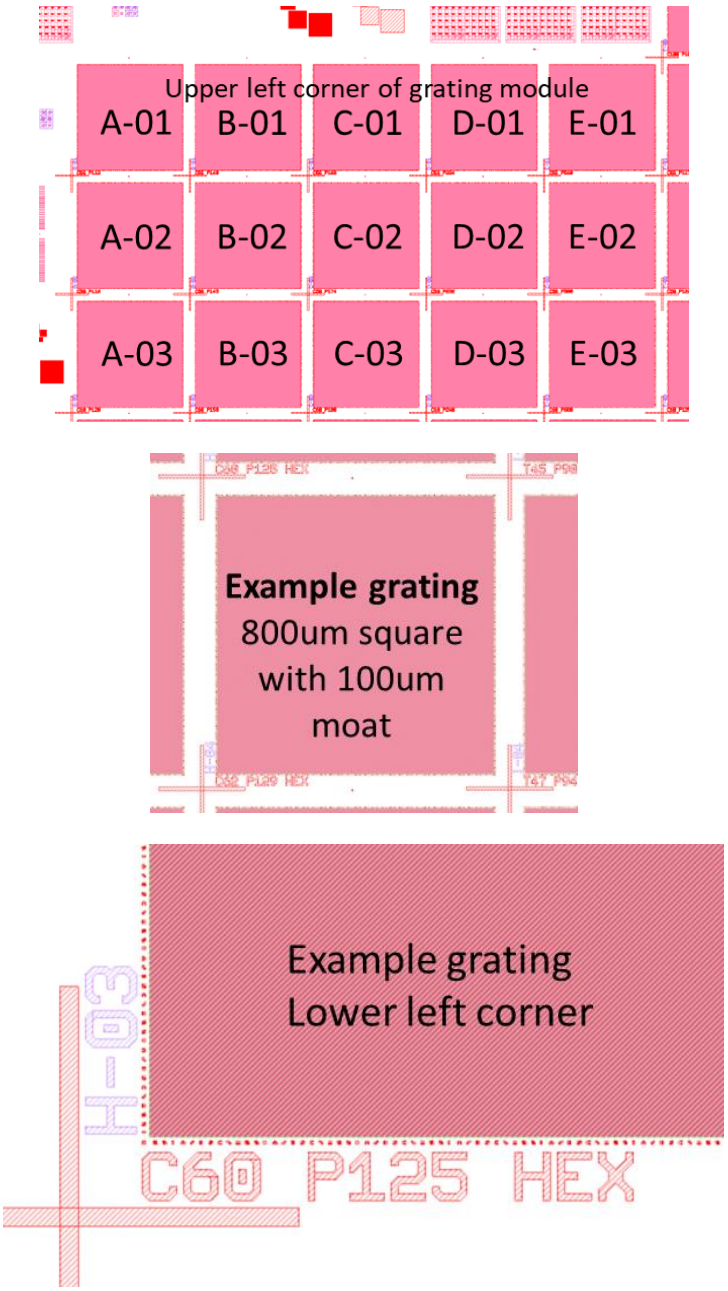

Figure 2: All main CD-SAXS/OCD gratings are 800 µm square with 100 µm moat in between, and include pattern rec for SEM/AFM around periphery, a large pattern recognition cross at lower left, grating label, and grid coordinates for locating them easily (columns named by letter, rows named by number). Example A-01 is upper left grating. Grating to right of that is B-01, grating below it is A-02, etc. as in diagram.

AMAG7 also 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 such as contour measurement and extraction, EPE, two-level structures, die-to-database tests, and more.

- DCP (dimensional control patterns) of all feature sizes and main pitch ratios in both x and y for line/trench/dot/holes, in a form factor easily measurable by CD-SEM or CD-AFM.
- OmniCleave: 500 µm wide cleavable structure which includes all the main CD and pitches for most of the gratings above for line/trench and staggered hole/dot.

- GI-SAXS gratings of L40P100, C60P120 and C60P125HEX with 1mm x 2mm pad sizes are also included.
- Electrical CD linewidth structures are included from 30nm to 250nm linewidths plus locations for measurement of sheet resistance. Available in both brightfield and darkfield varieties.
- Complex periodicity pitchwalk DOE module for Quad-/Hexa-/Octa-Patterning and EPE studies.
- OPC module: the latest OPC verification module from Mentor Graphics is included in triplicate and in both brightfield & darkfield polarities in both vertical & horizontal orientations.
- Random Polygon Pseudo-Logic patterns: Large regions of random polygon pseudo-logic in design rules of 90nm, 100nm, 110nm, 120nm and 130nm pitch are included for large-FOV SEM, contour extraction studies and die-to-database testing. The left portion of each also includes intentionally-induced contour errors for such testing.
- Intentional LER patterns

AMAG designs were originally meant to be thorough sets of tool characterization features, and since they were intentionally not OPC'd not tied to any set process so are flexible for targeting individual features of interest. These wafers are quite useful for tool characterization, optimization, development, calibration, monitoring, round-robin comparisons. Also they can be used for rating tool precision, accuracy, matching, navigation, pattern recognition.

A full OPC module from a major vendor and a DOE of pitchwalk and 2D random polygon fields for contour/EPE/D2D testing also is included, along with many other gratings with intentional roughness and added variation, 2-level overlay for finFET or VIT, variable film pad sizes, e-test module, staggered cleavable structures, and more. One section can be bladed and printed as a 2-level full set of overlay modules from different vendors and including Verniers for reference metrology. Onboard those chips are more large gratings allowing for two level dual damascene or fin/gate gratings, among other form factors. The overlay module also includes SEM overlay marks and allows testing of various overlay measurements along with see-thru imaging by HV-SEM.

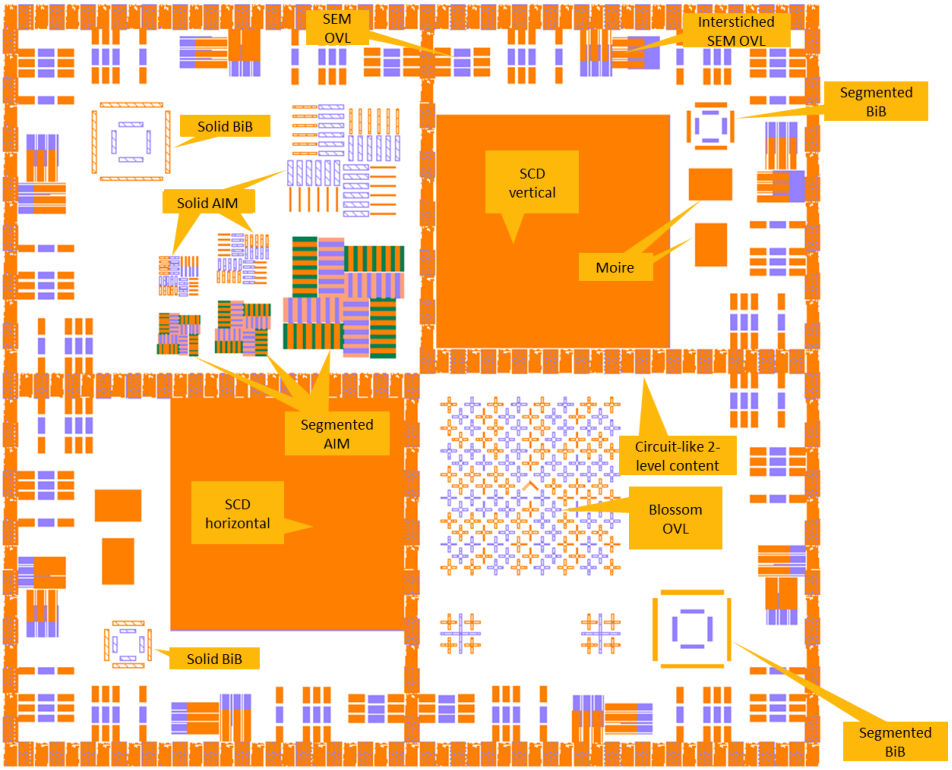

Figure 3: AMAG7 overlay test module can be printed two level and includes all major overlay target types and is sized at five different design rules with multiple steps of built-in intentional misalignments. Target also includes Verniers for reference metrology and SEM overlay marks and 2-level marks meant to be read by see-through HV-SEM.

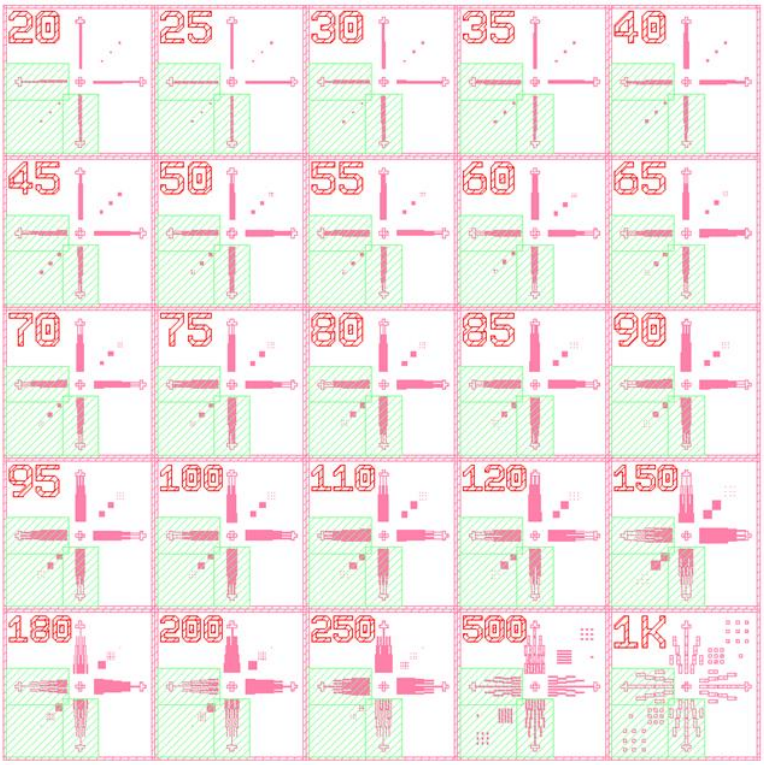

Figure 4: Dimensional Control Pattern (DCP) which is a set of L-bar-like features at many design rules with line, space, hole and dot all included, however they may print at a given condition.

One of the key issues with such test artifacts is often they come with restrictions for use or publishing results from the wafer supplier. However, wafers made with AMAG7, while the intellectual property embodied within AMAG7 designs and AMAG7 printed wafers is owned and copyrighted ©2020 by AMAG Consulting, LLC, customers purchasing AMAG7 printed wafers can be granted a limited license to use and publish target data acquired from AMAG7 printed wafers for which data shall then be treated as IP-neutral. Thus, many collaborative studies can now be enabled without IP issues.

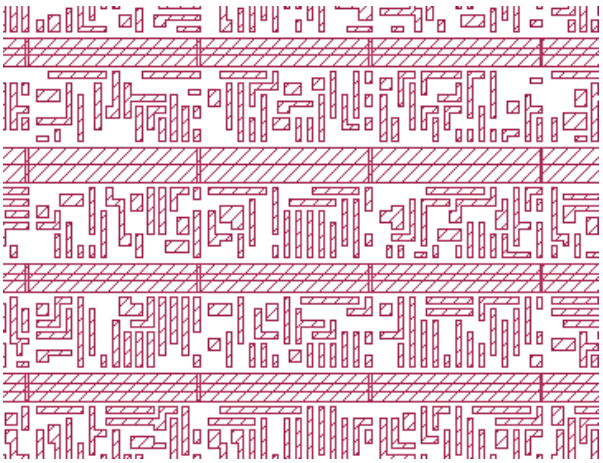

Figure 5: Random polygon pseudo-logic patterns to mimic 2D contours in complex circuit-like topographies, included as large 1 mm fields for contour large FOV SEM testing, contour extraction and D2D testing, at multiple different design rules. The edge also includes intentional random print defects to force variation from the design to make detectible errors for D2D detection testing.

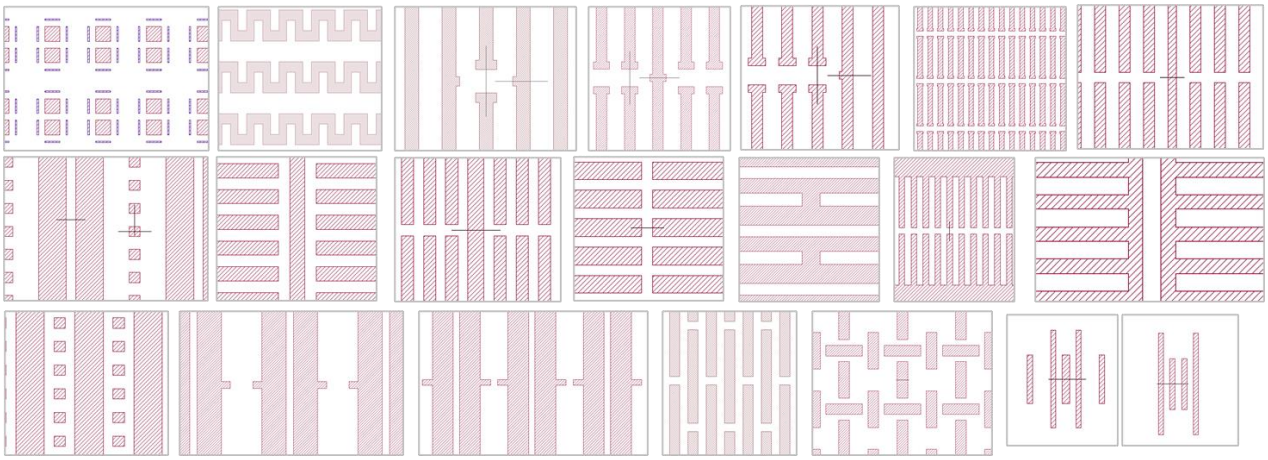

Figure 6: Example structures from the full Mentor Graphics OPC module included on AMAG7. This allows many complex and applicable tests to be run on standard targets of industry interest.

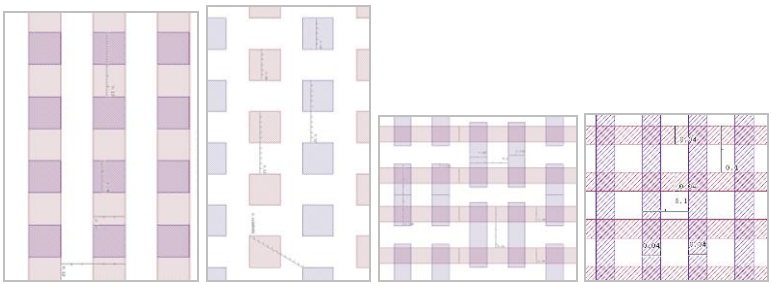

Figure 7: Two-level gratings in AMAG7, allowing damascene via-in-trench (VIT), dual exposure of C60 contact holes, gate layer over fins, and gate over fin crosshatched gratings, shown left to right.

AMAG TEST WAFER FOUNDRY

AMAG Consulting has revived and 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 and applications are becoming available for various applications for the development and tool supplier community, and new products leveraging the AMAG7 pattern can be developed to meet specific needs.

Initial product wafers currently being built are HAR holes, exposed with contact hole conditions and etched into 1 μm and 1.5 μm SiO_2 terminating on Si substrate, and a simple 100nm deep SiO_2 layer on Si patterned with the line/space pattern. Other stacks will get developed by adapting existing foundry processes to the new reticle as desired.

- HAR etched features
- 1-layer oxide etched features
- a-Si etched features
- poly etched features
- metal etched features
- CMP metals
- FinFETs, damascene trench or VIT
- 2-layer structures with overlay DOE
- Conformal films over topography
- Spacer DP
- ONO HAR
- and more.

GENERAL INITIAL LITHOGRAPHY PERFORMANCE

Initial lithography has been developed for two specific general hole and line/space conditions, and the first test wafers are coming available in a few simple stacks with more to come as processes adapted to AMAG7 pattern. Note that other features pattern at these conditions with relative success but such features can be directly targeted with optimized lithography for users in all cases below. For example, L30P90 resolves but bridges at this exposure but could be targeted to print.

AMAG7 L40P100 Line/space condition

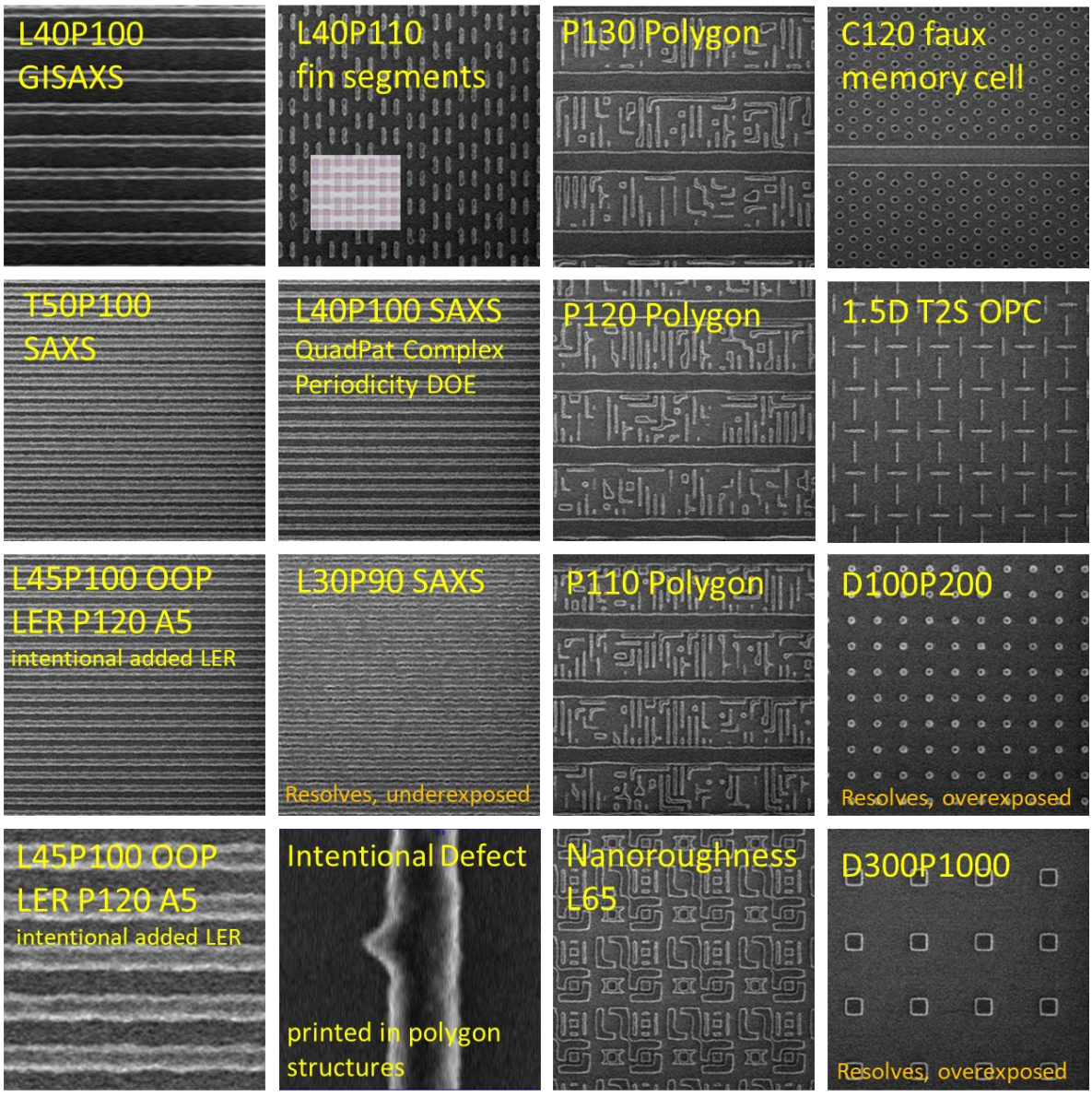

Figure 8: Examples of key AMAG7 lithographic features achieved with line/space lithographic conditions, optimized on L40P100.

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

AMAG7 C60P120 Contact hole condition

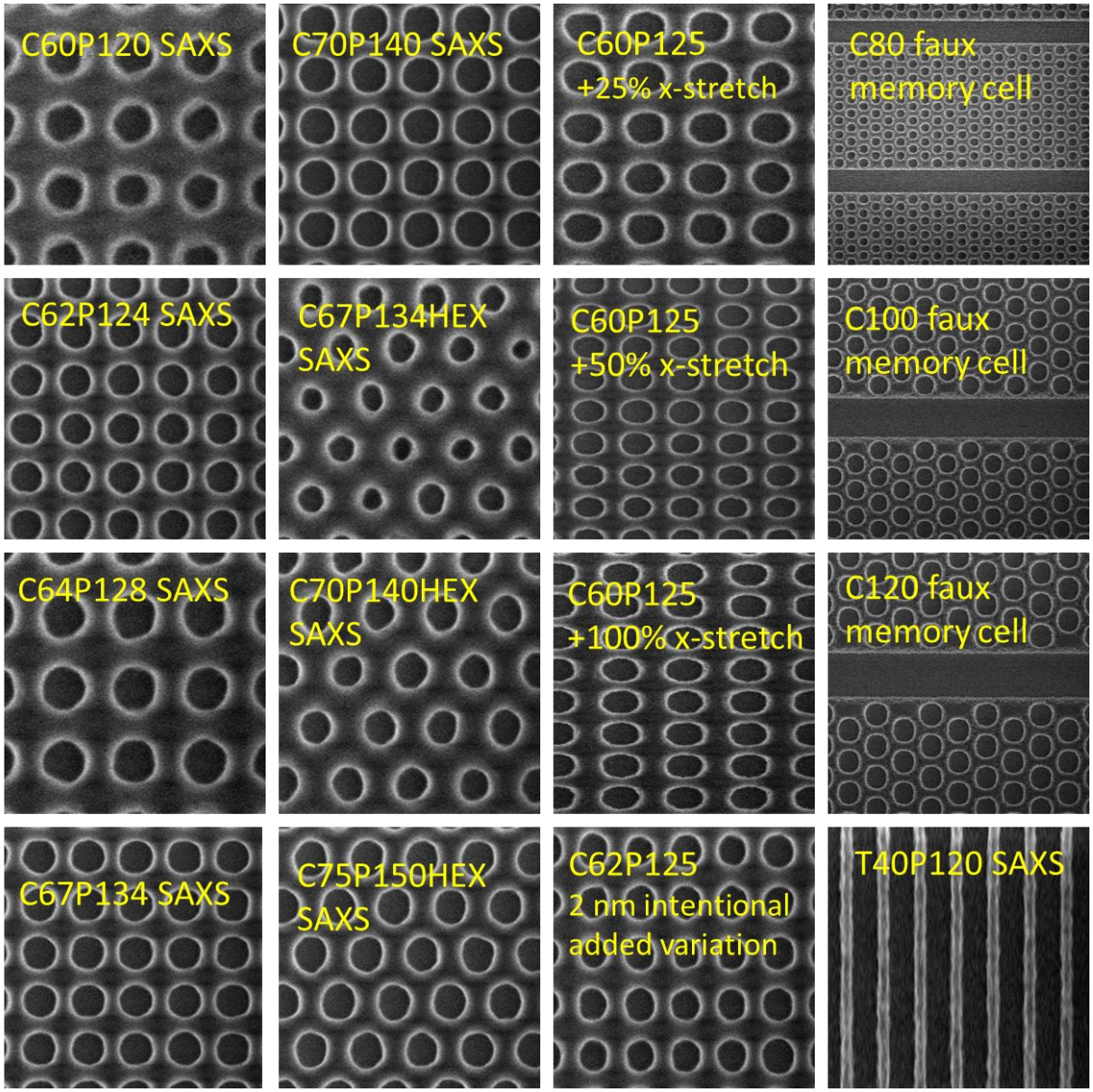

Figure 9: Examples of key AMAG7 lithographic features achieved with contact/via lithographic conditions, optimized on C60P120.

Most square array hole content prints down to 120 nm pitch at the condition specifically targeting C60P120. Hex hole content patterns pattern successfully at C70P140HEX. Trenches of 120nm pitch are also patterned successfully on same wafer, even if very wide.

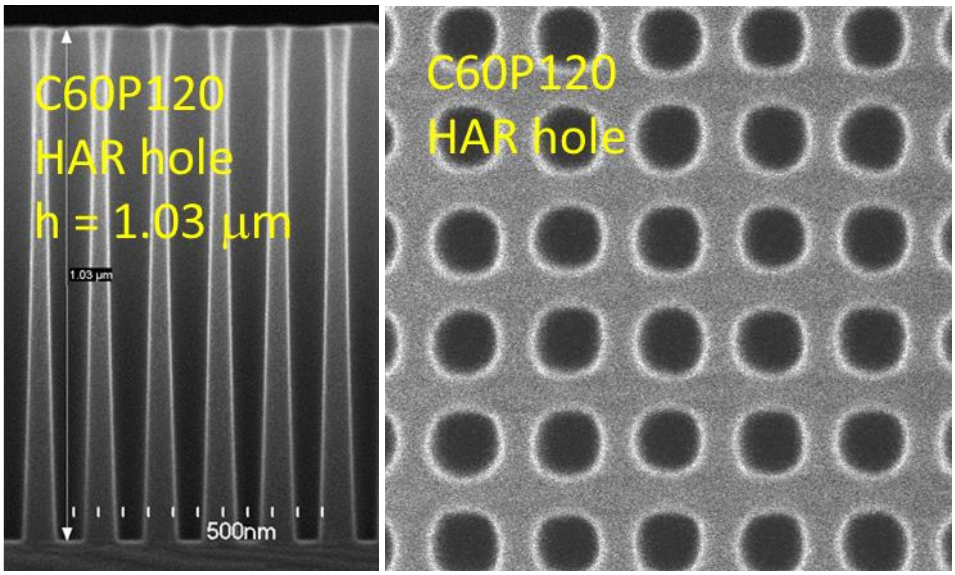

Figure 9: The first stack adapted to AMAG7 is to fabricate 1 µm deep HAR holes in oxide, as shown here.

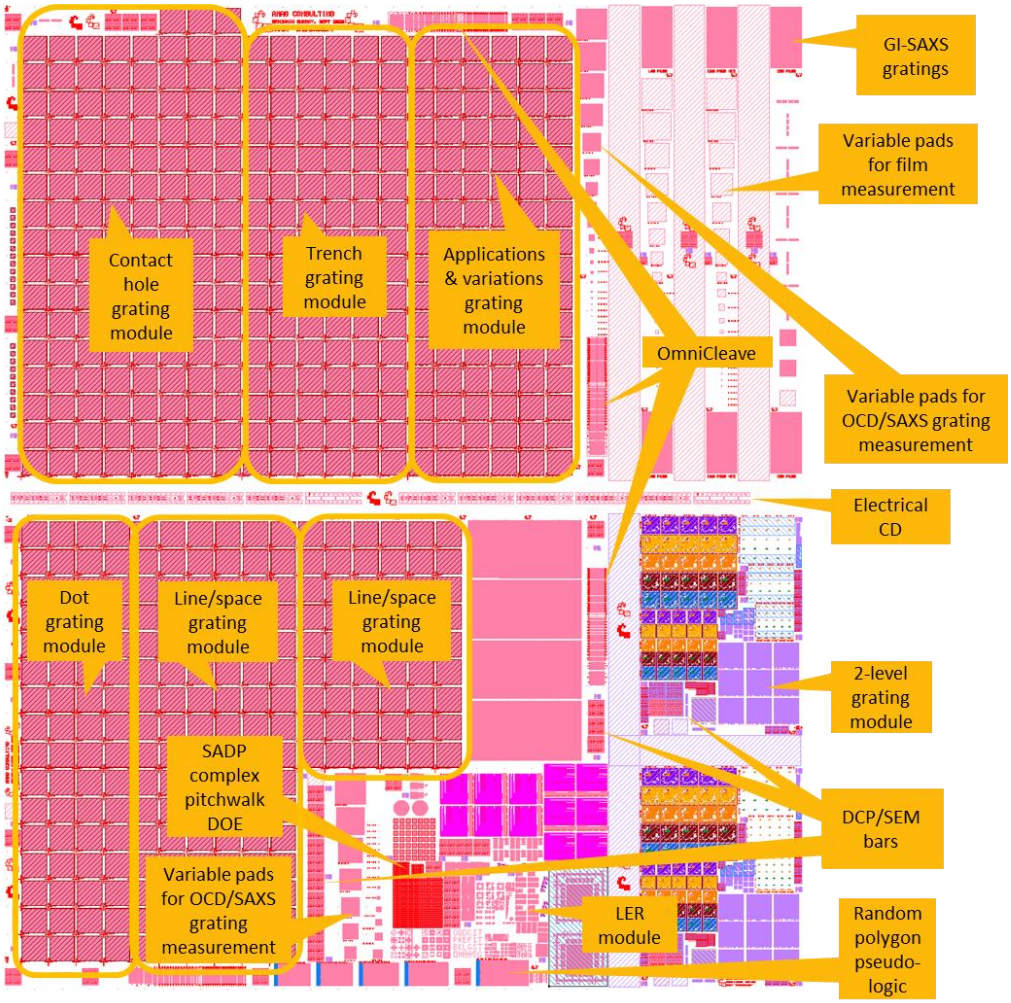

Figure 10: Floorplan of AMAG7 reticle, with more key features indicated.

CONCLUSIONS

The AMAG7 advanced metrology test reticle is available for a few initial process stacks including 1 μm and 1.5 μm deep HAR holes and line/space/hole in 70-100 nm oxide, and more stacks will get adapted to the new pattern as we move forward. This makes available IP-neutral test vehicles for many different test cases patterned with a very flexible reticle of features designed for usefulness to the metrologist of any tool type, and more use cases can be addressed as processes are adapted to this pattern.

ACKNOWLEDGEMENTS

AMAG Consulting acknowledges and thanks NY Creates fabrication facility for their efforts in achieving the initial lithography, and Benchmark Technologies for reticle fabrication. AMAG7 was designed as the world shut down during Covid-19, and getting it fabricated in these times was a major accomplishment, along with achieving the first lithography in spite of all the global supply chain issues facing our industry.

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