Airgrid with near-ideal structure for enhanced performance and reliability

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CMOS Image Sensor pixel scaling beyond 0.7um presents significant challenges in maintaining optical performance at the per pixel level. Sensitivity, color mismatch and crosstalk degrade significantly at this scale. Traditional metal or oxide grid material between color filters cannot provide sufficient optical isolation due to light absorption and transmission. An airgrid structure has been proposed in recent years [1] and released in limited products to address this challenge. The air-dielectric interface provides total internal-reflection that significantly reduces light loss and cross talk. However, current solutions still lack key structural features that can maximize performance [1], and mitigate reliability challenges, such as moisture penetration, of the airgrid structure.

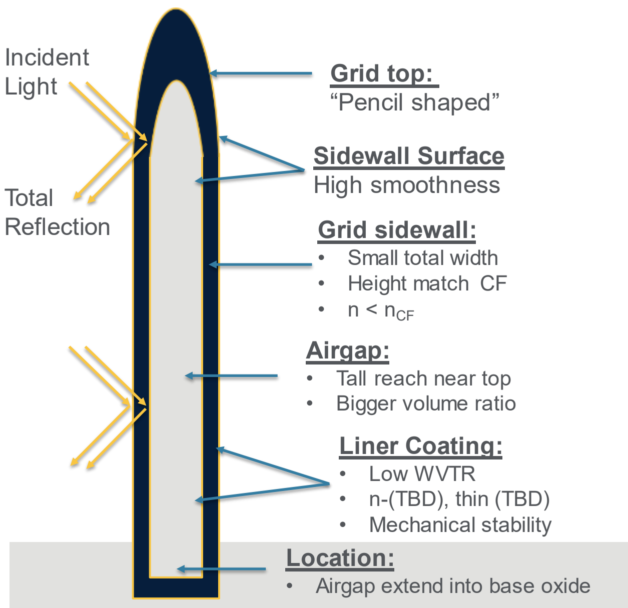

Figure 1. Illustration of an "ideal" airgap as grid structure

Applied Materials™ has developed a new design and process integration method to create a near-ideal structure that is optimized for maximum performance and addresses reliability requirements.

As shown in Fig. 1, an ideal airgrid structure should have following key features:

1. Narrow grid width compared to the pixel pitch size
2. Large airgap volume ratio (thin sidewall)
3. Airgap extends near the top of grid, and into base oxide
4. Rounded, narrow grid top
5. Low surface roughness
6. Height matches color filter thickness
7. High density surface with low Water Vapor Transmission Rate (WVTR)

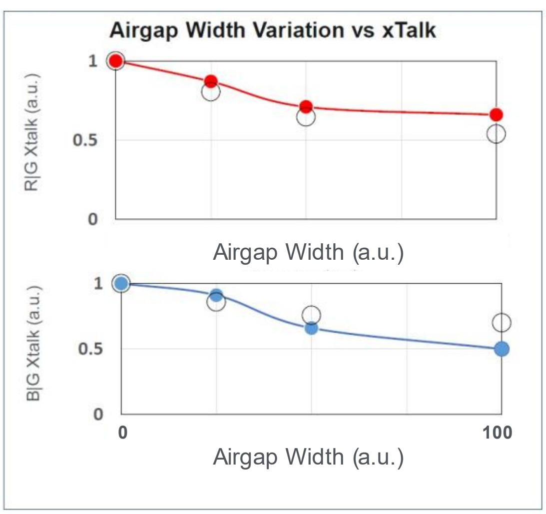

Figure 2. Simulation showing reduction of cross talk with different airgap width. 0 width represent a pure dielectric grid. A balance of isolation and grid footprint and structural integrity can be achieved for a pixel pitch around 0.6um design.

Through innovative integration and process co-optimization, Applied Materials has demonstrated the near-ideal structure for airgrid pixel isolation. Simulations show that such structures provide up to

50% reduction in cross-talk, reduce 4C mismatch by up to 80%, and increase sensitivity by 40%.

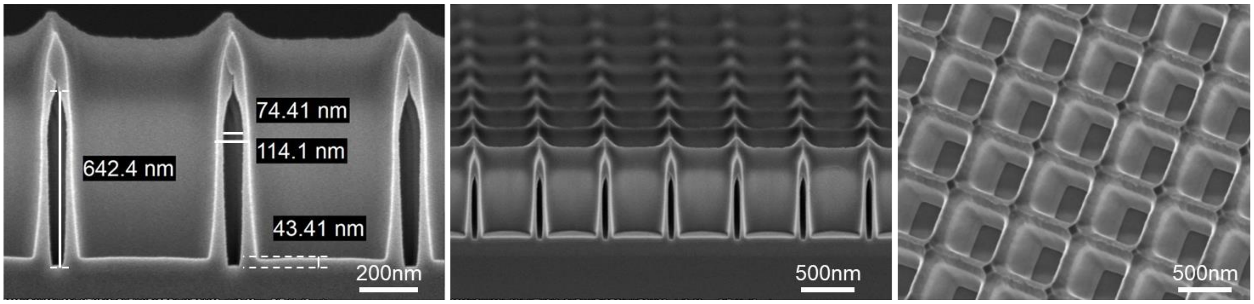

Figure 3 Left: near ideal airgrid structure, for a 0.64um pitch, with airgap height 642nm, width 74nm, total grid width 114nm, and airgap extended 43nm below. Middle and Right: array of highly uniform airgrid

Figure 3 shows the cross sections and a top view of a finished airgrid structure, for a 0.64um pitch pixel array. A large airgap volume is achieved, with minimum sidewall thickness of 20nm, and high uniformity across the wafer. The airgap inside the grid also extended 43nm into the grid base, as designed, for maximum optical performance.

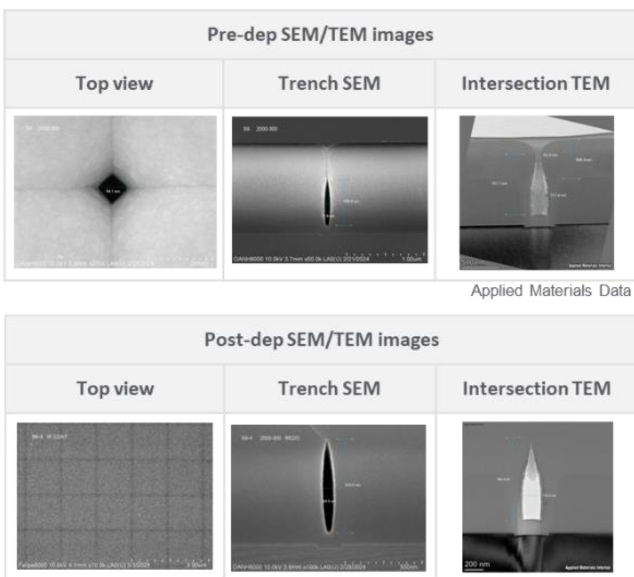

Figure 4. Top: post airgap forming, trench area is pinched off while intersections are still open. Bottom: HARP closes off intersection area without affecting trench area airgap

To enable HVM production, Applied Materials has developed a full module solution for 300mm wafers to reliably produce such ideal structure. Applied Materials Centris™ Sym3™ X etch chamber provides excellent cross-wafer uniformity, critical for maximizing structural performance while maintaining good structural margin for reliability and yield. Furthermore, the very low surface roughness from Sym3X is a key capability for optical performance. Applied Materials Producer™ HARP™ provides critical capability of controlled conformality with high quality oxide, to form specific morphology (pinch-off/seamless fill) at different locations on the structure, providing significant flexibility to adapt to specific process assumptions. For example, it is well known that an oxide deposition that fills a gap and pinches off on top will likely leave regions of the filled trenches not pinched off. This presents structural integrity issues that are not acceptable for reliability. The aforementioned HARP process provides controlled conformality to pinch off and seal the intersections, while not affecting the airgap structure in the trench area (Fig.4). To provide added protection for reliability, Applied Materials solution applies two major strategies: 1. High quality ALD passivation coating on the final structure. 2. Periodical separation of the airgap across a device area, so that even if any local region (a few pixels) has an airgap that is compromised, the failure does not propagate into rest

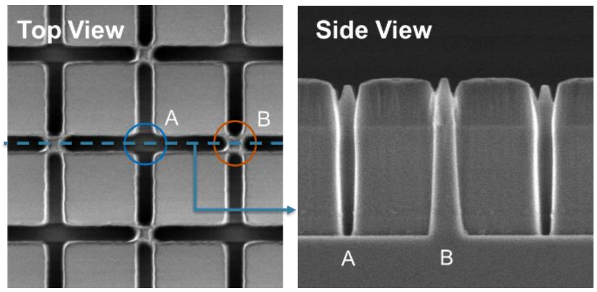

Figure 5. Top and side view of airgap grid with separated airgap regions by the B sites

of the device as illustrated in Figure 5, designed isolation of airgaps is implemented, and can be adapted for different designs, without affecting the active airgap structure and optical isolation performance.

To improve productivity, in-line metrology was developed to monitor structure at various steps to ensure production quality. In particular, Applied Materials Reveal™ offers inline SEM and FIB capability, provides fast in-line cross section view of the sample. Figure 6 shows the in-line FIB result, clearly showing the A-B site design for improved reliability as discussed above.

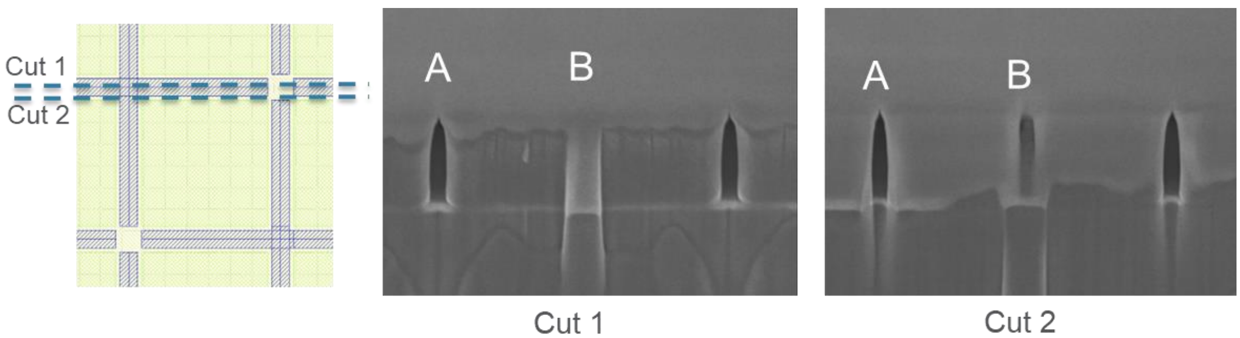

Figure 6. RevealTM in-line FIB cut showing alternating intersection with completed filled and hollowed design, for reliability

In addition, Reveal™ can generate high resolution 3-D reconstruction of the complex structure, through a delayering – imaging process and reconstruction algorithm.

Left image in Figure 7 shows a SEM image after de-layering process removing about 300nm from the top on the airgrid structure. The de-layering process was done on a sample area of 6um*6um. A series of

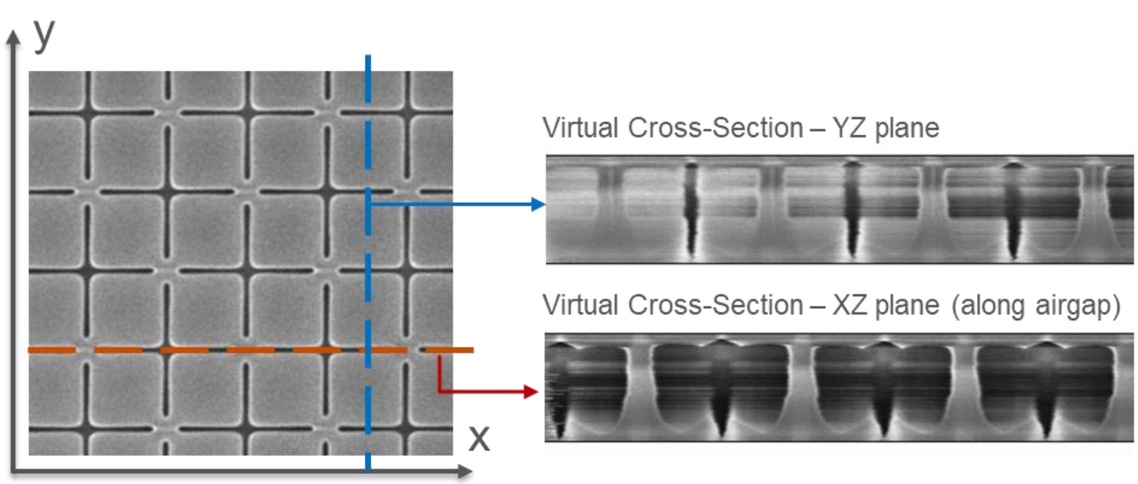

Figure 7. Left: SEM image of a delayered airgrid structure. Right: virtual cross-section of the airgrid structure generated by 3-D reconstruction of the airgrid structure from series of delayering images.

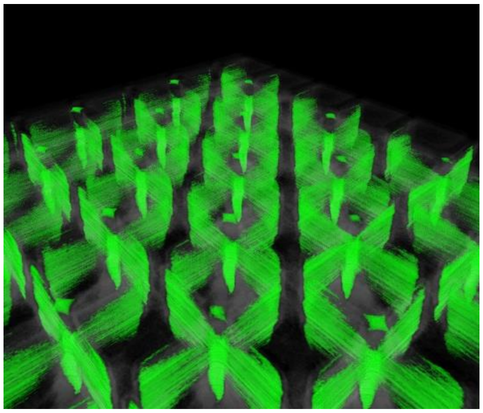

Figure 8, 3D reconstruction of the airgrid strucutre from series of delayered images of the structure

such de-layered structure images were obtained, at de-layering step size of 1nm. The delayered images were used to reconstruct a 3-D model of the sample, as in Figure 8. From the 3-D model, further useful analysis can be performed. For example, images on the right side of Figure 7 provides "virtual-cut" of the sample that is done at desired plane and any location.

For high-throughput inspection, Applied Material's ProVision^{TM} tool provides non-destructive measurement of structures that are covered by oxide. In this case, the airgap width, and the total grid width are measured, and a wafer map was generated based on measurements at 126 locations on the wafer. An example is shown below in Fig 9, where a mis-process wafer shows strong with-in-wafer non-uniformity. This fast inspection capability can provide significant value in production environment.

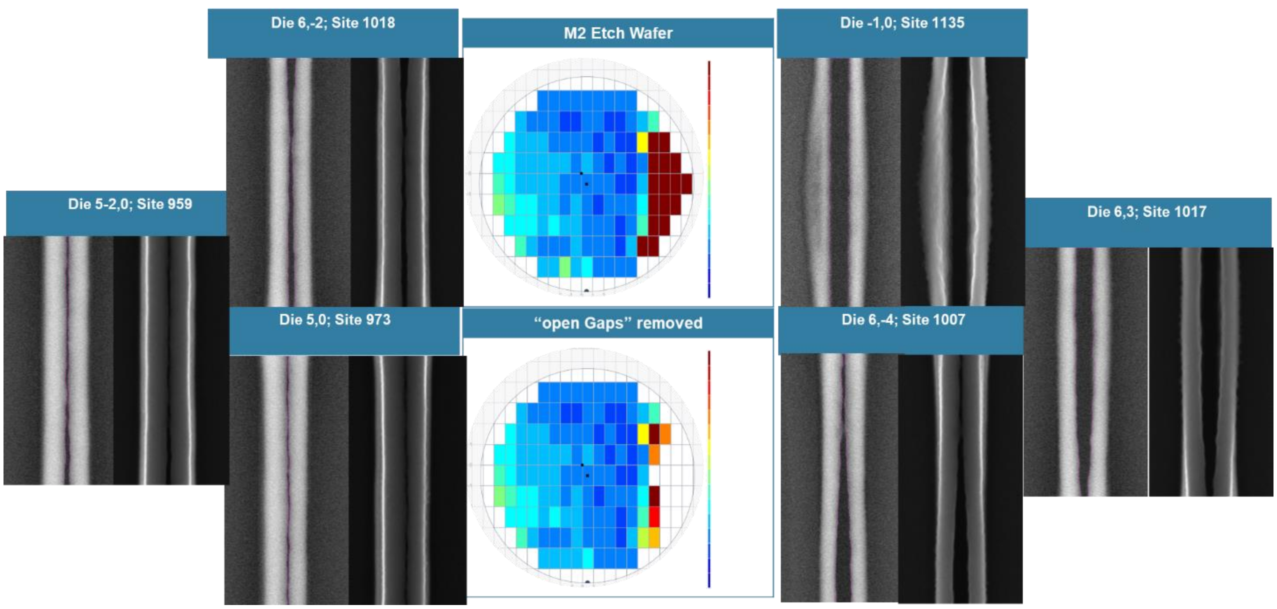

Figure 9, CD measurement and wafer map generated by non-constructive measurement my Provision^{TM}

References:

[1] P. Sungbong, et al, ISSCC 2022, Session 5, "A 64Mpixel CMOS Image Sensor with 0.56µm Unit Pixels Separated by Front Deep-Trench Isolation"