

and the virtualization of a test environment. These two concepts offer the ability to accelerate hardware verification and embedded software validation for multi-billion gate designs at all levels of abstraction — from virtual platforms to desktop FPGA prototyping and everything in between.

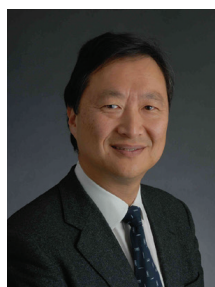
2021 portends even greater use of hardware-assisted verification technologies. In one potential scenario, a verification team's dream becomes reality with a seamless integration between individual hardware-assisted verification tools. This single robust environment couples tool intelligence with engineering best practices to make the verification task faster and smarter. It will make efficient use of all verification resources and streamline the efforts and collaboration of multiple teams.

Look Out for Curves Ahead in the Photomask Market

AKI FUJIMURA, CEO,
D2S

The photomask market is consistently adapting and innovating to keep pace with the rest of the semiconductor supply chain. As a result, while COVID-19 introduced challenges to global markets overall, sentiment among key decision makers within the photomask market segment remains neutral or positive about growth in 2021 according to the ninth annual eBeam Initiative Luminaries survey, completed in July 2020. Most respondents to the survey also predict that some leading-edge masks will have at least some curvilinear shapes on them by 2023.

In semiconductor manufacturing, the move to EUV for critical layers of leading-edge nodes, the proliferation of multi-beam mask writers, and the emergence of curvilinear mask shapes provide a lot of excitement



Aki Fujimura

and opportunities for the year ahead. Multi-beam mask writing has been in production use for a few years now. EUV for wafer lithography has entered production use and is seeing a high rate of innovation throughout the manufacturing process. In 2021, we should start to see at least some experimentation with curvilinear mask shapes being produced in mask shops.

Curvilinear mask shapes are desirable for improving resilience to manufacturing variation in wafer production. However, prior to production availability of multi-beam mask writing, it wasn't practical to write curvilinear mask shapes with the traditional variable-shaped beam (VSB) writers. Both Optical Proximity Correction (OPC) and Inverse Lithography Technology (ILT), techniques that compute the desired mask shapes in order to maximize the quality of wafer lithography, needed to constrain

themselves to specifying Manhattan shapes to be produced on the photomask. With multi-beam mask writers removing this constraint, and with ever increasing demand for precision on the wafer to improve process windows, curvilinear mask shapes are desirable for both 193i lithography and EUV

lithography. Some unique aspects of reflective masks in EUV add to the need for curvilinear shapes on EUV masks. In addition, for other reasons, EUV masks need to be written on multi-beam mask writers anyway, so there is no barrier to using curvilinear shapes.

With the write-time barrier solved thanks to multi-beam writers, defining and manipulating curvilinear mask shapes now becomes an opportunity for ILT. Until recently, ILT faced the problem of long runtimes. Fortunately, the incredible advances in graphic-processing units (GPUs) solves this

problem. The latest NVIDIA "Ampere" series of processors provide around 20 TFLOPS (tera-floating operations per second) with 7,000 to 10,000 cores using 7-nm full-reticle designs. Just as multi-beam writing using pixels makes mask writing speed independent of shape complexity, GPU-based algorithms are pixel-based, making compute time independent of shape complexity. D2S has announced its TrueMask® ILT designed specifically to take advantage of the power of GPUs to make full-chip curvilinear ILT practical.

2021 is the year photomasks are going to start to be curvilinear. While this will bring immediate benefits in the manufacturing world, it also presents long-term opportunities for the design world.

Life in the Data Era

ORESTE DONZELLA, EVP,
Electronics, Packaging and
Components Group; KLA
Corporation

We undoubtedly live in the data era — a digital transformation that has been further accelerated by the COVID-19 pandemic. The creation, storage, analysis, and transmission of data has become crucial to the advancement in mobile communication, data centers, automotive, and more recently healthcare. Accelerated by secular trends, like 5G networking and artificial intelligence, these markets will drive unprecedented growth of the semiconductor industry in the 12 months ahead and likely for several years to come.

In 2020, we saw strong demand across each of KLA's business segments (Semiconductor Process Control, Global Support and Services, and Electronics,



Oreste Donzella