Advanced Imaging via Pixelated Phase Masks and Inverse Lithography

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We describe the advantages and challenges of using Pixelated Phase Masks with Inverse Lithography methods for patterning random logic wafer patterns. A Pixelated Phase Mask (PPM) divides the entire mask area into a grid of square pixels where the pixels can be different mask states such as zero-transmission (chrome), zero-phase (unetched glass) or pi-phase (etched glass). By design and optimization of the pixel configuration, the PPM can form either an alternating Phase Shift Mask (PSM) to be used with highly coherent illumination or a phase edge style mask with off-axis illumination. Both styles of mask are well established methods of improving image quality. For this work, we use PPMs (example **Figure 1**) with strong off-axis illumination. In this configuration, PPMs act as variable high-transmission attenuated phase shift mask where the phase pixel configuration simultaneously optimizes OPC (Optical Proximity Correction) and SRAF (Sub-Resolution Assist Feature) generation. A pixel mask structure provides a convenient structure (gridded mask) for Inverse Lithography Techniques (ILTs). While OPC tools generally produce mask designs by iteratively evaluating small perturbations of the mask design with forward imaging calculations, ILTs transform target wafer intensity distributions to mask designs. In practice, ILTs can produce mask designs with more complex polygon arrangements and phase assignment. We find ILTs especially useful for chromeless PSM as a simple chromeless PSMs tends to produce wafers patterning with only a small range of resist widths on the wafer and that chromeless PSM designs need to diverge significantly from the target pattern in order to accommodate a useful variety of wafer feature sizes and configurations. We describe challenges and results of using a PPM for patterning a 65nm generation first level metal layer of a micro-processor. As features on the mask become sub-wavelength, thick mask effects become more significant. While thick mask effects complicate both the forward and reverse image calculations, they also help enable PPMs by allowing larger minimum pixel sizes and phase designs with near equal sized zero and pi-phase regions. PPMs with 3-tones (un-etched glass, etched glass, chrome) offer more flexible patterning capability compared to 2-tone PPMs (no chrome) style but at the detriment of a more complex mask making process. Mask manufacturing challenges are described including defect types unique to PPMs such as an Electro-Static Discharge (ESD) defect and the requirement of Ebeam based repair.

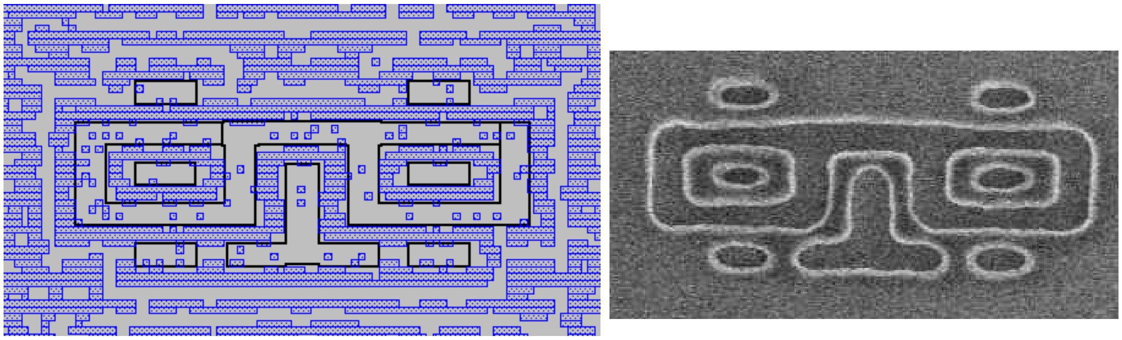

Figure 1 Pixelated Phase Mask (PPM) example: left illustrates the mask pattern where blue/dark region represents etched glass (pi phase) and gray/light regions represent unetched glass (zero phase). Black lines are added for a reference to the desired pattern. Right side shows wafer pattern from mask on left using a wavelength of 193nm, NA of 0.93 and cQuad illumination. Min pitch of pattern is 120nm.