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Maskless lithography

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Abstract

The high and rising cost of photomasks (largely driven by writing times exceeding 24 h) is driving the exploration of maskless lithography for applications requiring throughput about 1 cm^2/s which is about one tenth that of an optical projection exposure system. Achieving this throughput with charged particle lithography requires currents 10,000 times larger than those presently used and hence sets up the need for charged particle optics radically different from those being used today. Achieving this throughput with optical maskless lithography at the required minimum features sizes of 65 nm and below is a serious engineering challenge for the spatial light modulator. Meeting 10% or even 1% of the throughput requirement might still result in mask writing and inspection technologies that would lead to significantly less expensive masks. Furthermore, relaxing the requirements on control of individual edge positions (i.e., a fixed-shape projector) would significantly ease the above challenges.

Keywords: Maskless; Lithography; Electron beam; Optical lithography

1. Introduction

To try and avoid the high and rising costs of photomasks, two forms of maskless lithography are being seriously pursued. One is optical (OML), whose proponents claim enjoys no fundamental limit to throughput and the other is charged particle maskless lithography (CPML2) that is claimed to enjoy no practical limit to resolution.

Needless to say the above claims are oversimplifications. OML has recently been reviewed by Sandstrom, Hintersteiner and their colleagues at Micronic Laser and ASML [1] and will be only briefly covered here.

A notional requirement is an exposure rate of 1 cm^2/s and minimum feature size of 65 nm extendable to 45 nm for OML and to 25 nm for CPML2.

2. Definitions (Fig. 1)

Minimum Feature size (MFS): the nominal size of the minimum feature to be exposed on the wafer.

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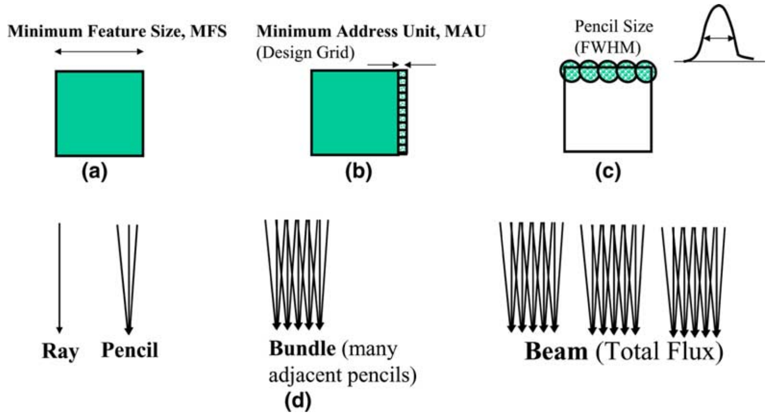

Fig. 1. Definitions.

Minimum Address Unit (MAU): the smallest increment by which we want to adjust the position of the edge of a feature (also called the design grid).
Ray: the trajectory of a single photon or charged particle.
Pencil: Ideally a collection of rays converging to a single point in the image; here, we mean a collection of rays converging to the best focus.
Bundle: A collection of pencils whose landing areas are contiguous.
Beam: The total flux of photons or charged particles in the system.
Column: A source and one or more lenses axially symmetric about an optical axis.
Space-charge blurring includes stochastic (scattering) and continuum (lens) effects.

For example a pattern generator employing a single pencil beam may have a pencil size (FWHM) the same as the MAU. But, as shown below, a more economical strategy is to have a pencil size much larger and adjust the current in the pencil to adjust the position of the feature edge (Fig. 1c). A more advanced pattern generator may employ a beam that is a bundle defining a MFS onto the wafer and adjust the positions of feature edges using a variable-shape technique. Some systems are now being developed feature a beam comprising an array of bundles.

3. Four limitations to throughput *W*

As pointed out above, we should aim for $W = 1\ \text{cm}^2/\text{s}$.

One well-known limitation is the dose required by the resist. For OML this, is usually expressed in mJ/cm^2; the development of increasingly powerful lasers for optical projection lithography at $10\ \text{cm}^2/\text{s}$ suggests that this is not a serious problem for OML.

For CPML2 this dose, usually expressed in $Q\ \mu\text{C/cm}^2$, is that used to bring about the required chemical change in the resist. In most instances the value of Q increases with the energy of the particle to keep constant the energy dissipated per unit volume in the resist.

Obviously $W \leqslant I/Q$ and so to maintain $W = 1\ \text{cm}^2/\text{s}$ for $Q = 1\ \mu\text{C/cm}^2$ (corresponding to a sensitive resist) we need $I \geqslant 1\ \mu\text{A}$. This might just be practical for an MFS of 200 nm in a single-bundle system but not for 25 nm (Fig. 2). Hence a multi-bundle system seems to be needed.

The speed at which the beam is scanned across the target can also limit throughput. For example, if we employ in a CPML2 system a stage speed of v cm/s and sweep width y cm then for a single bundle system $W \leqslant vy\ \text{cm}^2/\text{s}$; for a n-bundle system the $W \leqslant nvy\ \text{cm}^2/\text{s}$. So for $n = 1$ and $y = 100\ \mu\text{m}$, the stage speed must be at least 100 cm/s. This is about ten times faster than today's stages and may cause unacceptable blurring for dwell times exceeding