A PennWell Publication
Microlithography WORLD
Summer 1996

FEATURE

Scanning projection for large-area lithography

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A unique scanning projection system can pattern the large substrates used for flat panel displays (FPDs) and multichip modules at 4–6 µm resolution. This method provides a versatile production tool with high yield and low cost of ownership.

Photolithographic techniques are used to create complex patterns in the electronics industry over a wide range of dimensions. While the patterning requirements of the diverse segments of the industry may be different, the tools and processes are similar, as is the need for continually improving productivity. As large area lithography develops, methods previously employed for integrated circuit manufacturing are adapted for other purposes.

In the manufacture of integrated circuits, the critical dimensions have fallen and the die sizes have increased over the last 20 years. Chips today have 0.5-µm features patterned accurately across 20-mm areas—a total of perhaps 6×10^9 features. Continued aggressive development of new optics, tools, and processes is underway to reduce the resolution to 0.25 µm or less [1]. The primary tool for critical-layer lithography is the high numerical aperture step-and-repeat projection camera, with typically 5× reduction. Sub-half-micron resolution is obtained by utilizing high NA reduction lenses, deep UV light sources, such as excimer lasers at 248 nm or 193 nm and phase shift masks. As the die size increases beyond 22 mm, step-and-scan systems will displace the current stepper technology.

Due to the high cost associated with excimer-laser-based step-and-repeat lithography tools, several manufactures have adopted a “mix-and-match” strategy using high-throughput steppers for their noncritical layers. With this strategy, critical sub-micron levels are produced on excimer-based steppers, and the less critical levels are produced on a 1:1 lithography tool that employs the elegant Dyson catadioptric lens system.

A number of lithographic techniques with low to intermediate resolution are used to manufacture large area products, such as printed circuit boards, multichip modules (MCMs), and flat panel displays. In the flat panel industry, step-and-repeat projection tools (with field-stitching) are now the dominant force for active matrix liquid crystal displays (AMLCDs), which require 1.5-µm resolution for critical transistor levels, but less resolution for traces and transparent electrodes [3]. Proximity printers are being used for the fabrication of color filters. Global market size for FPDs was $11 billion in 1995, and is expected to reach $22 billion by the year 2000 [2]. The rapidly growing FPD and MCM-D markets — and their intense competitive pressures — create a demand for cost effective intermediate resolution lithography tools with large area capability.

The mix-and-match strategy also applies to the manufacture of FPDs, which have critical and noncritical levels of lithography. The same Dyson 1:1 projection lens system that has proved so valuable in IC manufacturing has been adapted to pattern the layers of MCMs and FPDs requiring resolution of 4–6 µm. The large areas of these devices require a unique scanning exposure system. The resolution requirements for electro-luminescent (EL) and plasma displays are ≥4 µm; intermediate resolution lithography systems can meet 100% of the requirements for patterning these devices. Such tools can also be used in the production of pixelated color filters that require resolutions of ≥4 µm.

In the MCM-D industry line/space size and via size are presently at 8–10 µm, trending downward toward 5 µm in the future. Tool sets that can provide lithography resolution of ≥5 µm with a large depth of focus (DOF) are required. In both the FPD and MCM-D industry, yield is a key driving factor that rules out contact or proximity lithography tools.

Flat panel displays are fabricated on large float-glass substrates. Major current production is now being done on 360 × 465-mm

Reprinted from the Spring 1996 edition of **MICROLITHOGRAPHY WORLD**

substrates, and future third-generation plants will handle 550 × 650-mm or larger panels. Substrates are also very thin (0.7 to 1.1 mm), flexible, fragile, and difficult to handle automatically.

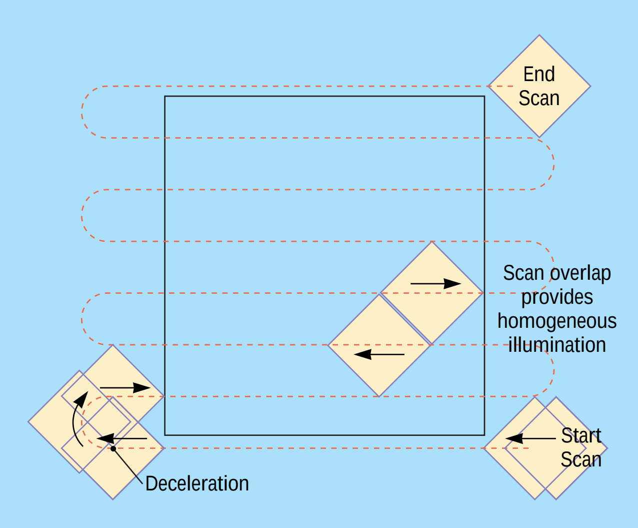
Unlike semiconductor wafers, which are lapped and polished flat to 1–2 µm, the flatness of typical float-glass flat panel substrates is in the range of 10–15 µm. In order to accomplish good CD control, the lithography tool must have a DOF in excess of this variation.

Alignment of the flat panel substrate often requires working with low contrast fiducials etched into transparent indium tin oxide. In the MCM-D area, very thick resists that have low light transmission at the alignment wavelengths (540–600 nm) often cover the fiducials, making alignment of a number of layers very challenging.

Large area scanning tool

Tamarack Scientific has addressed the problems of intermediate resolution lithography on large difficult substrates [4] with the development of scanning projection tools (model 300 LGPX) that are able to align and expose substrates up to 450 × 500 mm. This approach uses a projection lens with a relatively small image field but a sufficiently high NA to achieve usable resolution (CD) of ≤4 µm. The large substrate is exposed by scanning a diamond shaped image 30 mm on a side in a serpentine fashion over the entire area (Fig. 1). At present there are a number of these production scanning projection tools in the FPD industry with tools for the MCM-D industry soon to be delivered. Tamarack is presently under contract with the United States Display Consortium (USDC) to develop a larger tool with the ability to expose substrates up to 840 × 1025 mm with higher throughput and automation.

Figure 1

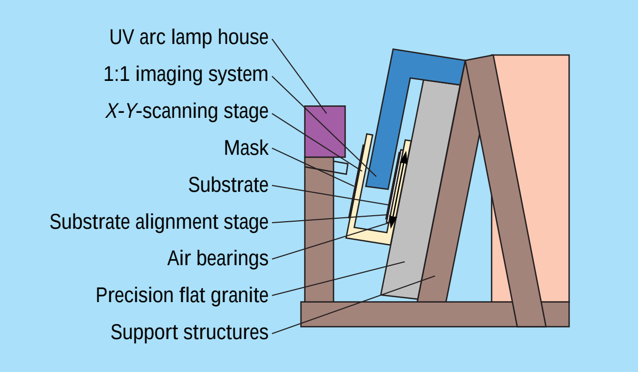


Scanning a large substrate area with a diamond-shaped exposure field measuring 30 mm on a side.

Large-field scanning

Scanning over a large rectangular field is achieved using a large air bearing stage to move the mask and substrate simultaneously in a serpentine pattern past the exposure field. The mask and substrate are held parallel to one another 200 mm apart with the projection lens rigidly supported between them, as shown in Fig. 2. UV energy from a high intensity mercury arc source, also rigidly mounted, provides the diamond-shaped 30 × 30 mm illumination beam at the mask. A Dyson-type catadioptric projection lens with an erecting prism integrated into the assembly images the mask onto the substrate. Exposure is controlled by measuring the beam intensity before the exposure and regulating the scanning velocity to achieve the required dosage.

Figure 2



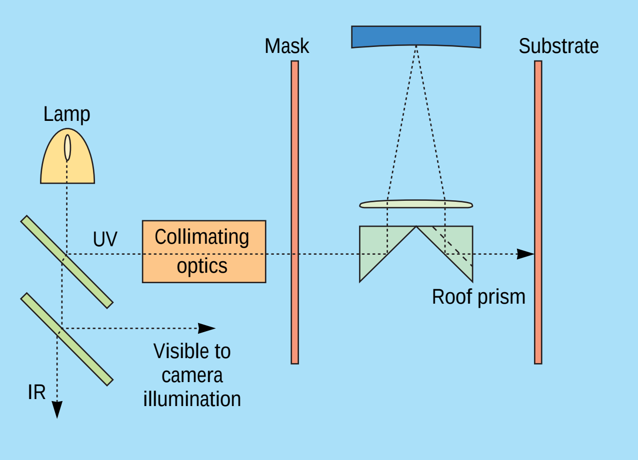
The large-area scanning projection system.

Homogeneous exposure of the 450 × 500-mm substrate is achieved with scanning projection, as shown in Fig. 1, where the diamond-shaped projected images are shown being scanned over the substrate. (In reality the substrate and mask are scanned past the stationary lens and illumination.) From this diagram, it can be seen that the overlap of adjacent parallel scans results in a homogeneous exposure of the artwork and substrate.

The displacement between adjacent scans is 1/2 the diagonal of the diamond-shaped image field, so that every point of the substrate is exposed twice; and while the absolute exposure doses of the two scans vary with position, their sum (and hence the overall exposure energy) is constant. Any errors in the homogeneity of the UV intensity over the exposure field, or in the distance between adjacent scans, will result only in second order perturbations of the overall exposure dose. A very homogeneous exposure results.

Each scan is started outside the active substrate area, so that the stage is accelerated to full scanning speed before any active area is exposed. This way the exposure time (= field diagonal / scanning speed) is made accurate to 2% all over the exposure area. The overall uniformity of the exposure dosage (in mJ/cm^2) over the entire substrate is ±2%.

Figure 3



Exposure and illumination optics.

Table 1. Relationship between numerical aperture (NA), resolution (RES), and depth of focus (DOF) for $\lambda = 436$ nm

NA	RES (µm)	DOF (µm)
0.07	6.2	89
0.08	5.5	68
0.10	4.4	54
0.12	3.6	30
0.14	3.2	22

Projection lens

The projection optics is a broadband UV (350–450 nm), chromatically corrected, catadioptic lens based on the Dyson concept. The lens (Fig. 3) is configured with right angle and roof prisms to produce an erected image that is ideal for scanning. This design provides a short object to image distance, and is inherently free of distortion. The lens is rigidly mounted to granite and located between the mask and substrate.

The numerical aperture (NA) of the lens can be varied from 0.07 to 0.14 with an aperture in front of the aspheric mirror. This NA flexibility allows a process engineer to optimize for resolution vs DOF.

A lithographic system for flat panels or multichip modules must cope with substrates that are not flat — typically with >10-µm surface topography. The optical system needs to provide adequate resolution and DOF to obtain the specified CDs across the nonflat substrate. Best resolution is obtained with high NA and largest DOF, with a low NA. The flexibility to select a lens NA with the best resolution/DOF trade-off is necessary to handle such substrate topography. Table 1 shows the relationship between numerical aperture, DOF and the resolution, and allows an engineer to select the best numerical aperture for his process.

Illumination source

Exposure energy is provided by a high radiance 2000-W mercury arc lamp that produces *i*-, *h*-, and *g*-line radiation. An ellipsoidal reflector collects over 80% of the arc lamp energy.

Beam-forming optics homogenizes the beam and allows the fraction of the projection lens entrance pupil filled by the illumination to be varied. Partial coherence (σ), variable over the range from 0.3 to 0.8, can be utilized to obtain additional DOF to optimize the lithographic process. The illuminator system, shown in Fig. 3, provides an exposure intensity of over 2000 mW/cm^2 at the substrate plane.

In addition to providing the high intensity, broadband exposure suppresses standing waves that can be a problem with a number of resists. Some resist, photo-definable polyimides and color filter materials used in non-IC lithography require tuning the exposure wavelength to obtain optimum results. Fortunately most of the resists used in the industry have been formulated to be exposed with actinic radiation produced by a mercury arc lamp. Dielectric bandpass filters in the illumination then allow optimizing such processes without excessive reduction of exposure energies. The lamp system also provides visible light (577 nm) for through-the-lens (TTL) alignment.

Focus and planarization

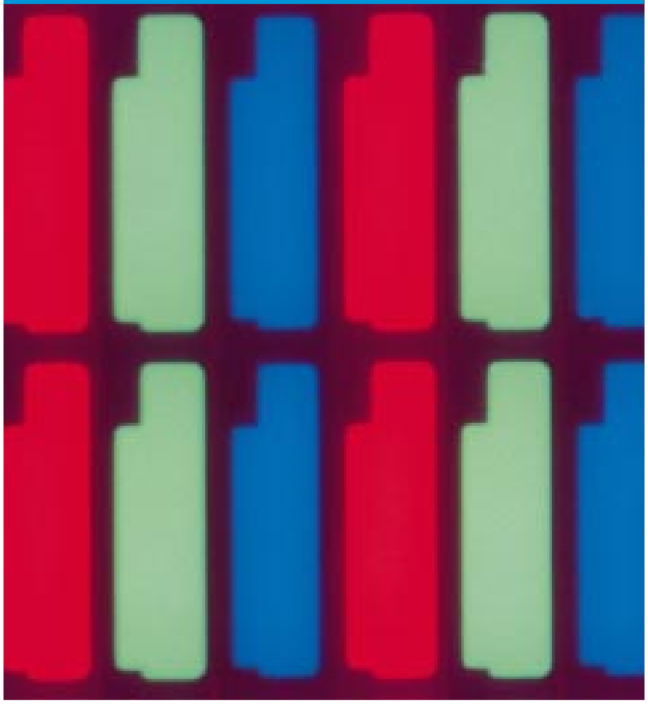
A uniform focus is of paramount importance to achieve high yield patterning with a large area lithography tool. For this reason, a noncontact air gauge measures the resist surface at three locations on the substrate. The air gauge approaches the resist surface to within 5 µm but it never touches the resist. A digital encoder attached to the air gauge provides an accurate (1 µm) measurement of the three widely separated locations on the substrate, and feeds the data to the computer that calculates the necessary correction to focus and planarize the substrate. Subsequently, the substrate is moved in the *Z*-direction by three independent actuators, which have a resolution of 0.5 µm, thus focusing and planarizing the substrate.

Alignment

Automatic alignment of the mask to the substrate is accomplished by a TTL system. This is normally difficult in an all-refracting projection lens corrected for UV exposure, but not for the 500–600-nm alignment wavelengths [5]. With the catadioptric projection lens used in the Tamarack model 300 LGPX system, the mask and substrate are in focus in the 350–450 nm exposure range and at the alignment wavelength. Thus alignment can be done with a TTL system composed of a dual-magnification-objective/CCD camera and a commercially available pattern recognition system.

Computerized pattern recognition allows the distance separating the desired and the actual mask and substrate fiducial positions to be measured and analyzed to achieve stage alignment in *x*, *y*, and θ. Following alignment, the system automatically verifies that the programmed (go–no go) alignment specification set into the process recipe has been obtained. The system routinely achieves an alignment accuracy of better than 2 µm.

Figure 4



A pixelated color filter used in FPDs.

Computer control software

Operation of the scanning projection tool is accomplished from an industrial PC (Windows environment) that allows the process engineer or operator to load in a number of process recipes. Once the recipe has been entered or called up from memory, all the operator needs to do is load a panel and push a button, and the tool will automatically process the panel. The total number of recipes that can be stored is over 100, limited only by the disc space.

Throughput

The throughput of an exposure system is always dependent on such process parameters as substrate size, exposure energy, and the time required to unload and reload a substrate. The scanning projection system is capable of processing over sixty 360 × 465 mm substrates/hr with a 150 mJ/cm^2 dosage.

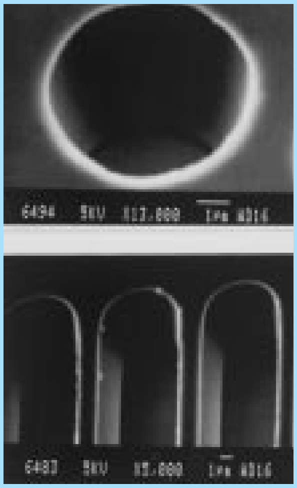
Field performance

Resolution and DOF performance of the system in the field has followed theoretical predictions. Planar Systems purchased the first 300 LGPX scanning projection tool for the development of their full-color, thin-film electroluminescent displays [6]. According to Planar, the system resolution is 5 µm or better in their 5-µm-thick sprayed-on resist. In addition to etching, Planar also utilizes a lift-off process wherever possible to reduce cost and avoid corrosion and etch damage through resist pinholes.

Table 2. Resolution of lines and vias in thick positive resist

Resist thickness (µm)	Exposure dose (J/cm²)	Resolution lines (µm)	vias (µm)
8	1.0	4	4
19	2.0	5	7
38	6.0	6	8

Figure 5



Four-µm features in an 8 µm AZ 4529 resist.

Photoimagable color filter materials as shown in Fig. 4 have been successfully exposed in the field at two different LCD manufactures using the 300 LGPX. Color filter materials are basically negative working and have been formulated to operate at 365-nm wavelength. Experiments at the Tamarack lab (with rather crude manual coating and developing) have easily demonstrated resolutions of 5–6 µm in 4-µm-thick Fuji Hunt or Shipley materials.

Excellent thick-resist, high-aspect-ratio results have been demonstrated in the positive resist used in MCM-D applications (Table 2). Figure 5 shows a micrograph of 4-µm features in 8-µm-thick AZ 4529 resist using this process.

Photomasks

A major issue for the 1× scanner is the availability of large area photomasks. Currently there are few sources for large-area masks. In the US, such masks can be obtained from Photronics in Colorado Springs, CO. In Japan, Hoya has been providing masks for proximity and projection printers for some time. Large area masks can be generated on a laser pattern generator, such as those manufactured by Micronic in Sweden, and Poly Scan in Tucson, AZ. It is also possible to photocompose a large area mask on a flat panel stepper.

In the US, the technology and infrastructure for large area masks are currently being addressed by ARPA and USDC. This effort is necessary in order to remain competitive in FPDs and MCM-Ds.

Excimers in the future

Processing of MCM-D modules can be simplified if the polyimide material can be directly ablated, rather than exposed and developed. Catadioptic projection lenses have been tested on a prototype scanning laser projection system with an industrial XeCl (308-nm) 150-W laser to ablate polyimide coated MCM-D substrates and polyimide films. Innovative optics have been developed and patented to provide wall-angle control during ablation.

A natural extension is to use the excimer laser to provide the short wavelength energy to expose the photoresist. Good results were achieved on 2-µm-thick *i*-line resists in limited experiments with an attenuated source. The basic concept can be extended to DUV lasers and resists to increase resolution and DOF.

Conclusion

With the scanning projection approach, the size of the substrate is no longer a restriction. Large areas can now be projection-printed with intermediate resolution down to 4 µm. Currently, development is underway to provide capability of aligning and exposing 840 × 1025 mm substrates, which are used for plasma displays. Tamarack also plans to investigate resolution enhancement methods, such as increasing the NA of the lens and optimizing the UV source by varying the partial coherence, off-axis illumination with the goal of improving the resolution to 2 µm. With large substrate and high resolution capability, future high throughput, high-yield scanning exposure tools will be capable of patterning 200 billion features on a single substrate for whatever applications arise. ■

Acknowledgments

The author wishes to thank Planar Systems/ARPA for the partial funding ofF the first model 300 LGPX scanning projection exposure tool to be utilized in Planar's development of thin-film, full-color electroluminescent displays. Also, we want to thank USDC/ARPA for the continued cost sharing support in the development of a second generation tool.

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