immersion leadership

Breaking through the 1.0-NA barrier: the 1.2-NA TWINSCAN XT:1700Fi

by Christian Wagner

During the past two years, 193-nm immersion lithography has moved from conceptual R&D to developing and testing the first full-field immersion scanners. In October 2003, ASML produced the first immersion SEM images on the 0.75-NA TWINSCAN AT:1150i. During the first half of 2004, we conducted subsequent immersion testing involving 16 ASML customers in Veldhoven. This helped to alter the industry's lithography roadmap by integrating ArF immersion technology into the exposure solution set for the 65-nm and 45-nm process nodes, with potential for even smaller resolution.

At present, the AT:1150i proto tool as well as several XT:1250i and XT:1400Ei immersion systems are operating in the field, leading to significant immersion experience and continued learning. In July 2005, ASML elevated immersion technology to the next level when we introduced the world's highest numerical aperture lithography system, the 1.2-NA TWINSCAN XT:1700Fi. These systems will begin shipping the first quarter of 2006.

As shown in Figure 1, the XT:1700Fi provides an improvement in resolution of 30 percent compared to the XT:1400E, at the same k_1. Semiconductor manufacturers can utilize the XT:1700Fi for volume production at either the 45- or 55-nm nodes. We expect that the tool will be used down to 45-nm half-pitch resolution in flash memory IC manufacturing.

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The increased NA makes using polarized illumination very beneficial, whereas for the NA < 1 systems, polarization will be used predominantly in R&D. For the 1.2 NA, region polarization will be introduced for high-volume manufacturing. A polarized illumination system provides improved contrast and exposure latitude at full throughput. With an NA this high, polarization enhances resolution by 5 nm, from 50 to 45 nm.

These SEM images shown in Figure 2 (printed with the XT:1400Ei) show that the combination of immersion and polarization enables a depth of focus of higher than 1 μm for 55-nm dense lines at a k_1 of 0.27, using polarized dipole illumination.

Figure 1

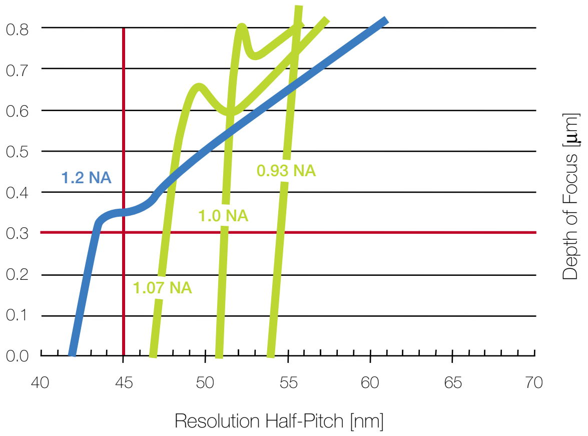
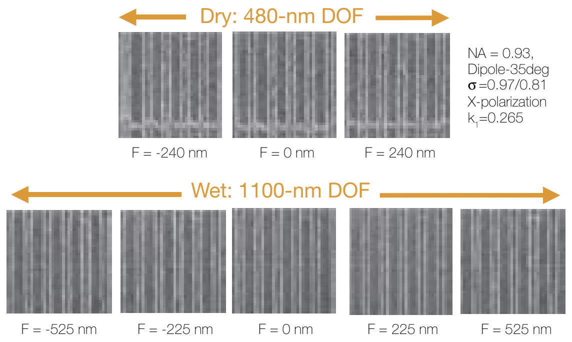


Figure 2



NA = 0.93,
Dipole-35deg
σ =0.97/0.81
X-polarization
k_1=0.265

The nature of hyper-NA lens design combined with the required tight aberration tolerances make these lenses exponentially more complex. Working with Carl Zeiss, a new catadioptric lens design was developed, which combines refractive components with mirrors to create a hyper-NA lens that is cost effective to manufacture while maintaining a size consistent with other ASML systems. This design supports a field size of 26 x 33 mm, consistent with today's systems.

Carl Zeiss obtained the required mirror-manufacturing accuracy from experience with astronomy applications, and particularly from building the EUV optics. Besides the fact that the lens-element diameters are smaller than those of the XT:1400E, the incidence angles of the optical rays on the lens elements are also smaller. This means proven polishing-and-coating technology can be used. The designers focused on finding a solution relying on one optical axis to ease adjustment and integration of the lens into the scanner body. As a result, standard (refractive lens) mounting technology can be used, and object and image orientation are the same as in refractive lenses, making it hard to distinguish this catadioptric lens from its refractive predecessors.

Fluid handling on the XT:1700Fi has been perfected for productivity and processing flexibility. The immersion showerhead has a set of features supporting the use of both hydrophobic and hydrophilic materials.

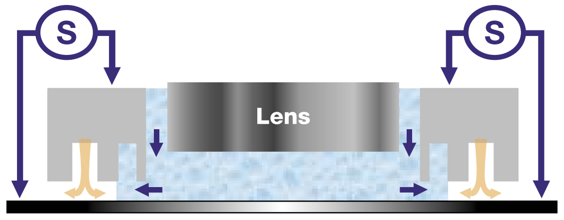
- Low-flying height above the wafer stabilizes the meniscus, including servo control for optimum dynamical stability
- Air curtain for active water containment

Both developer-solvable topcoats as well as low-leaching resist-only processes are supported, resulting in optimum productivity using cost-effective track configurations.

Figure 3 shows an illustration of the immersion showerhead, where the "S" indicates the servo control and the air curtain is indicated by the orange arrows on either side of the two-dimensional cut. In actuality, the air curtain encircles the water.

Figure 3

Servo-controlled immersion showerhead



One of the major challenges to fast implementation of immersion lithography has been immersion-related defects. While bubbling has been an issue for the early prototypes, the problem has now been solved with the redesigned hardware already implemented on the XT:1250i. Regarding processing defects, tremendous progress has been made in the past 18 months. Defects are reduced from more than 10.000 to less than 50 for state-of-the-art processes. Figure 4 shows the defect reduction progress for both patterned and bare wafers. Still, process optimization will be one of the key R&D topics for the coming six months.

Besides allowing for maximum process flexibility, the immersion showerhead also minimizes water evaporation. Evaporation leads to wafer cooling, which imposes a challenge for immersion overlay. The 7-nm single machine overlay target is achieved through further improvement of thermal control. The wafer table is thermally conditioned using high thermal conductivity materials to counteract residual cooling effects.

Additionally, with the XT:1700Fi, throughput is targeted to match the state-of-the-art dry throughput of the XT:1400E at 122 wafers per hour (see Figure 5). This is achieved by speeding up the closing disk overhead from ten seconds on current tools to two seconds on the XT:1700Fi. The closing disk is needed to close the immersion showerhead during stage swap to allow continuous flow of water, ensuring thermal stability and optimum water purity. Like the XT:1250i and the XT:1400Ei, the XT:1700Fi is based on the dual stage concept, where dry wafer metrology and wet exposure work in parallel for maximum throughput (see Figure 5).

Figure 4a

Defect reduction progress overview

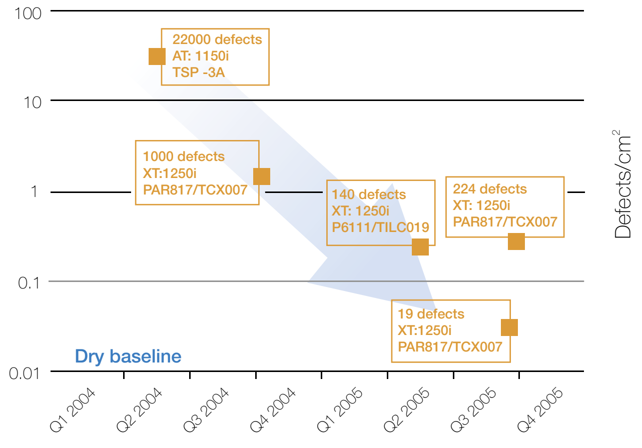
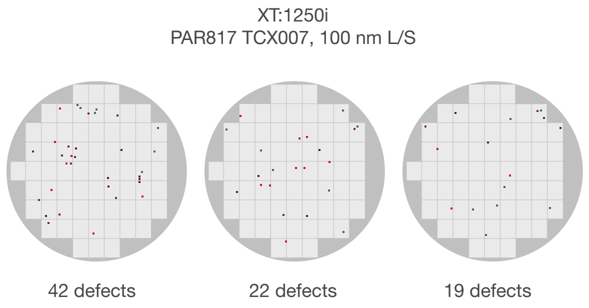


Figure 4b

State of the art defectivity results



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Technology leadership

- **XT:1700Fi: Industry's highest numerical aperture system (NA 1.2)**
- **Capable of 45-nm half-pitch resolution in Flash memory manufacturing**
- **Field size of 26 x 33 mm at max NA (1.2)**

Further extension of immersion technology

With water as the immersion fluid, the theoretical limit in NA is the refractive index of water. The practical limit for lens design is estimated at approximately 1.3 NA. This would result in 40-nm half-pitch resolution with a k_1 of 0.27. The concept of increasing NA further with high-index fluids has attracted substantial interest. For 193-nm, several fluids have been identified with indices varying from 1.53 to 1.64.

In addition to high-index fluids, high-index glass materials might be required to enable the super-high NA lens designs. In time, availability of appropriate fluids and lens materials will determine whether this technology extension will be viable, or whether alternatives such as EUV will dominate the lithography roadmap. ■

Figure 5

Current "State-of-the-Art" Dry ArF Scanner: XT:1400E