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Gas applications in lithography

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Introduction

Lithography is a key enabling process with very demanding requirements. Shrinking feature sizes will raise the bar even further. These increasing requirements on the process side will lead to increasing quality requirements for materials. This article provides an overview of existing gas applications in lithography and implications for the future.

The photolithography process

Photolithography is a key enabling and very critical process during semiconductor chip manufacturing. It always occurs at the beginning, and any defect occurring during the lithography process impacts the quality of subsequent process steps.

Smaller feature sizes require a better optical resolution. As the resolution depends on the wavelength of the light, illuminating systems with increasingly smaller wavelengths had to be developed. The current lowest available wavelengths for high-volume manufacturing are193nm and 248nm and are used at the most critical layers.

Excimer lasers

The light sources used to produce the desired wavelengths are excimer gas lasers and are fed with gas mixtures containing halogens and noble gases. Krypton-Fluorine excimer lasers emit light with 248nm, while Argon-Fluorine lasers generate photons at 193nm. Both belong to the Deep Ultraviolet part of the spectrum and are therefore called DUV lasers (in contrast to EUV, which is Extreme Ultraviolet light).

High-precision processes require high-precision starting materials

As the requirements on the precision of the lithography process are getting higher, equally precise quality control of the laser gas source material is mandatory.

Meeting the stringent requirements for mixture accuracy and gas purity are crucial for a high-quality light generation process. Gas contaminations as well as non-precise gas mixtures affect critical laser parameter like power output, target wavelengths, and lifetime.

Other gas applications within lithography

While gas mixtures for laser sources are probably the most obvious gas-related processes in lithography, there are a couple of well-established and a few rather new gas applications:

- Nitrogen for general purging
- Helium for heat transfer (cooling)
- Carbon dioxide as a laser gas and for latest-generation, defect-free illumination
- Hydrogen as a cleaning and shielding gas for EUV lithography

Nitrogen for general purging

Nitrogen is the most commonly used inert gas. The purity requirements of the lithography application are very demanding, requiring multiple-step purification.
Nitrogen is supplied to semiconductor fabs by on-site generation or in cluster parks by pipeline. On-site plants use cryogenic distillation to take nitrogen from the air, which contains 78%, and purify it to 99.999%. Gas companies have standard plants available for up to 50,000 m^3/h capacity. Some plant designs enable purity of 99.9999%, which saves equipment and power costs for additional purifiers.

Helium for cooling

Helium is used for cooling optical lenses in lithography. As the helium content in air is very small (0.0005%), it is not economical to extract it from the air. Instead, Helium is extracted from natural gas sources. Having access to several sources spread out globally can enable a secure supply.

As Helium is a limited resource, some industrial gas companies have developed solutions for Helium recovery, which makes possible the re-use of this scarce material.

Carbon dioxide for immersion and EUV lithography

Carbon dioxide has had many applications in the industrial gas industry, but its use in lithography is fairly recent.

In state-of-the-art immersion tools, CO_2 substitutes some CDA (clean dry air) to prevent the "big bubble effect." CDA has been used to shield the immersion hood against ambient air, but can form bubbles in the waters, which can potentially deflect the light beam and then cause defects in return. This effect gets more pronounced for smaller nodes for two reasons:

- Smaller features are more affected by even small deviations of the light beam.
- The increasing use of multi-patterning leads to higher throughput requirements, which then leads to a faster scan speed with the increasing risk of entrapping more CDA bubbles.

CO_2, with its superior chemical/physical properties (compared to CDA), does not form big bubbles. As CO_2 is applied at a critical spot (at the wafer/photoresist/lens interface), there are very stringent gas quality requirements.

For EUV, CO_2 is used as a laser gas. The new source architecture is changing the light generation concept, switching from a direct light source (excimer lasers) to an indirect light generation (a CO_2 laser beam hitting a tin droplet, leading to the generation of EUV light).

While these two applications require the same molecule (CO_2), the application and purity requirements are totally different. Having several different types of sources (ranging from natural wells over industrial production to biochemical routes) is challenging, as all these sources have unique types of contaminations. Gas companies can supply CO_2 as ultra-high purity gas (99.9997%) or as food grade, which is then purified on-site.

As the CO_2 production and purification is mostly designed to meet the requirements of the beverage and food industry, this does not automatically guarantee that a specific source is equally suited for semiconductor applications.

A tight quality control is therefore crucial, not only verifying food criteria, but also meeting the needs of the semiconductor industry. As an alternative to food quality, higher grades are available like 6N (= 99.9999%) and better.

Hydrogen as a cleaning and shielding gas

The development of EUV as a next generation lithography technology is proceeding. The small wavelength of 13.5nm will enable customers to process wafers for 10nm, 7nm, and smaller nodes.

EUV uses a different light source architecture, involving liquid tin droplets. These tin droplets can cause tin depositions on the reflecting optics, leading to a reduction in light power. To prevent this, Hydrogen is used to form volatile tin compounds, which can be pumped away, preventing a reduction in the amount of photons available for illumination. Compared to other gases like Nitrogen, Hydrogen has a low absorbance for EUV light, making it the gas of choice wherever a EUV light beam is passing through a chamber.