GIST develops groundbreaking eco-friendly dry photoresist... Expected to improve sustainability and efficiency of next-generation semiconductor processes

- Professor Sukwon Hong's team in the Department of Chemistry developed an innovative, eco-friendly heat-based dry photoresist that implements high-resolution extreme ultraviolet (EUV) patterning with simple heat treatment using domestic technology

- By presenting an eco-friendly and economical next-generation nano-micro integrated circuit manufacturing process, it is expected to increase sustainability and improve EUV lithography resolution, productivity, and yield... Published in the international academic journal 《Small》

▲ (From left) Professor Sukwon Hong of the Department of Chemistry, doctoral student Dowon Kim, Dr. Jinhwan Byeon, and master's student Jaeboong Ahn

A Korean research team has developed an innovative, eco-friendly dry photoresist* that can be implemented with simple heat treatment. This is expected to contribute to the sustainability and efficiency of semiconductor manufacturing processes by overcoming the limitations of existing processes and proposing an eco-friendly and economical process for manufacturing next-generation nano-fine integrated circuits.

The Gwangju Institute of Science and Technology (GIST, President Kichul Lim) announced that Professor Sukwon Hong's research team in the Department of Chemistry, in collaboration with Dr. Chan-Cuk Hwang's research team at the Pohang Accelerator Laboratory (PAL), developed an extreme ultraviolet (EUV)*-responsive photoresist for manufacturing nano-fine integrated circuits, and developed an eco-friendly heat-based dry process method by implementing nano patterns using the EUV of the PAL 10D beamline.

* photoresist: A photosensitive (light-responsive) polymer material used to form fine circuit patterns. Generally, when irradiated with light of a specific wavelength such as ultraviolet (UV), deep ultraviolet (DUV), extreme ultraviolet (EUV), or electron beam (e-beam), it causes a chemical change and has the characteristic of selectively dissolving or hardening.

* extreme ultraviolet: Light with a wavelength band of approximately 10 to 100 nanometers (nm; 1 nm is 1 billionth of a meter) between the X-ray and deep ultraviolet (Deep UV) spectrums. It has strengths in precise work such as high-resolution imaging, spectroscopy, and material processing, and in particular, extreme ultraviolet equipment can dramatically increase productivity by reducing the semiconductor exposure process steps.

Extreme ultraviolet (EUV) lithography* is a cutting-edge semiconductor manufacturing technology that plays a key role in improving the performance of next-generation electronic devices by engraving circuit patterns much finer than a hair on silicon wafers with light of a wavelength of 13.5 nanometers.

As circuit patterns become increasingly finer, conventional wet processes are at risk of collapsing the fine patterns of extreme ultraviolet photoresists due to the surface tension of liquid chemicals. This leads to quality problems such as reduced resolution* and increased line edge roughness (LER), which become more serious as devices become finer.

* lithography: A key process for forming fine circuit patterns in the manufacturing process of electronic devices. It is a technology that uses photoresist and light of a specific wavelength (ultraviolet, extreme ultraviolet, electron beam, etc.) to form a desired pattern on a substrate (wafer).

* resolution: In the photolithography process, it refers to the minimum size that can be transferred when exposing a mask pattern to a wafer. In other words, it indicates the limit of the minimum line width that can be implemented, and the better the resolution, the more precisely the fine patterns can be formed.

* line edge roughness (LER): Indicates the degree to which the edge of the pattern deviates from an ideal straight line. That is, it refers to the fine unevenness or irregularity of the pattern edge. Such irregularity can affect the electrical characteristics and reduce the performance and reliability of the device.

The dry process method is attracting attention as a next-generation technology because it reduces the use of solvents, which are hazardous substances in the lithography process, prevents pattern collapse, and can implement higher-resolution patterns.

However, the existing dry process method requires dedicated equipment and is expensive, and it also has environmental and safety issues due to the use of etchants*, which are hazardous chemicals, so new technology development is necessary.

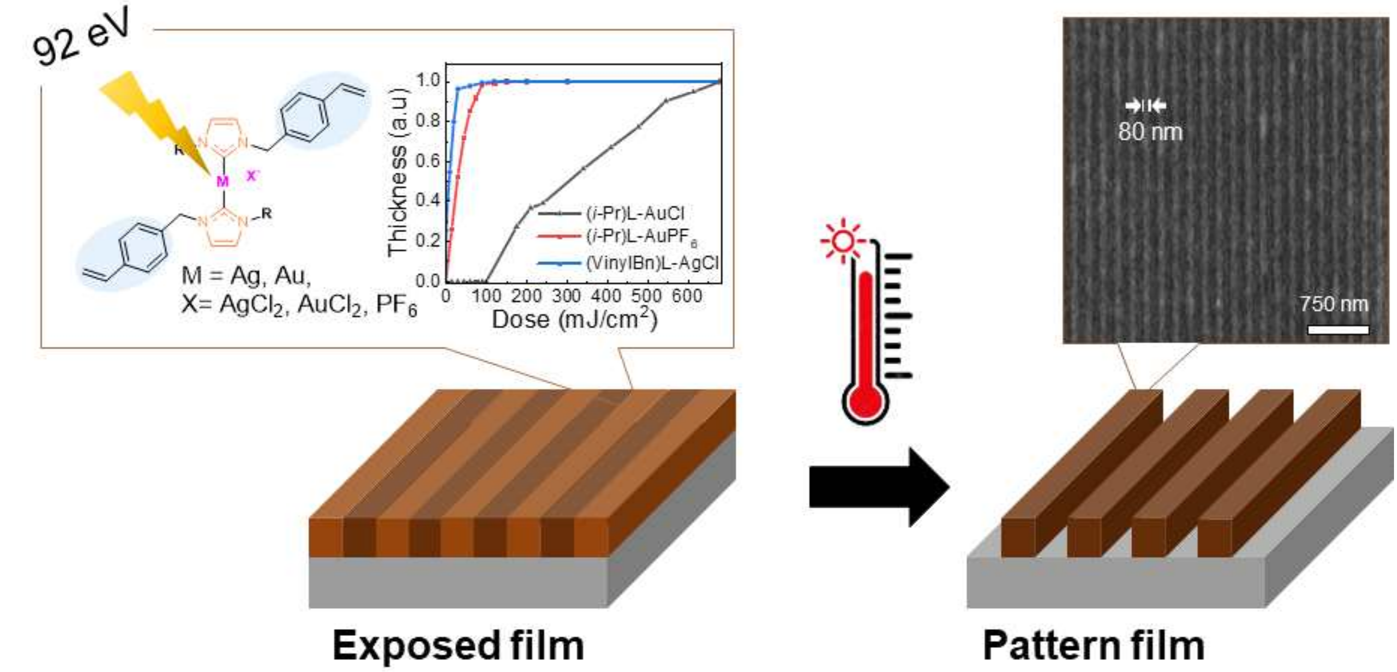
* solvent: A substance used to dissolve other substances, and is highly toxic and volatile, causing burns when in contact with the skin.

* etchant: A chemical substance used to selectively remove specific substances during the production of semiconductor circuits. In the semiconductor manufacturing process, it plays a role in precisely cutting the thin film layer on the substrate (wafer) into the desired pattern in the process of selectively removing specific thin film layers (oxide films, metal films, etc.) formed on the wafer (substrate).

The research team synthesized a material with excellent extreme ultraviolet sensitivity that responds sufficiently even at an exposure dose of 100 mJ/cm2 or less and reaches a state where there is no further change using a self-developed photoresist, and succeeded in implementing an 80 nm nano-pattern through an optimized heat-based dry process.

Existing dry processes that do not use etchants have limited patterning efficiency due to low EUV absorbance in organic-based single-molecule structures, and in polymer structures, there were limits to the size and sensitivity of the patterns that can be implemented due to the difficulty of the dry development process.

* exposure dose: The total energy of light required for a photosensitive material to form a desired pattern in a lithography process.



▲ Development of a heat-based dry development photoresist. The EUV absorbance of the EUV photoresist developed in-house was confirmed, and a heat-based dry process method using polymer formation caused by EUV was developed to successfully implement an 80 nm-level pattern.

The N-heterocyclic compound structure* developed by the research team has excellent stability while being able to form a metal-ligand bond. By optimizing the metal-ligand structure, excellent photoreactivity and sublimation were secured, and by applying a new heat-based dry process method, it was confirmed that nano-patterns could be implemented while maintaining high sensitivity.

As a result, a material with a sensitivity of 90 mJ/cm2 was applied to the dry process to implement an 80 nm-level pattern, and two international patents (PCT) were applied based on this unique technology.

* N-Heterocyclic Compound Structure: N-Heterocyclic Carbene (NHC) is a Carbene (Carbene, :C-) ligand with a heterocyclic structure containing nitrogen (N). NHC has strong Lewis basicity and stability, and is widely used in organic catalysts, metal catalysts, and organic electronic materials.

Professor Sukwon Hong said, “This research achievement is significant in that it implemented high-resolution EUV patterning with only a simple heat treatment process using domestic independent technology, and through this, developed an innovative, eco-friendly heat-based dry photoresist. This dry photoresist process is expected to contribute to improving the resolution, productivity, and yield of EUV lithography by reducing the amount of raw materials used and applying an eco-friendly process compared to existing processes, thereby increasing sustainability.”

This study, supervised by Professor Sukwon Hong of GIST and co-corresponding author Dr. Chan-Cuk Hwang of Pohang Accelerator Laboratory, was conducted by GIST doctoral student Dowon Kim, Dr. Jinhwan Byeon, and master's student Jaeboong Ahn as joint first authors, with research funding from the Nano and Material Technology Development Project of the Ministry of Science and ICT and the National Research Foundation of Korea. The research was conducted with the goal of developing core technologies for future dry processes, and the results were published online in the international academic journal 《Small》 on January 23, 2025.