Comparative Analysis of Positive Photoresist and Negative Photoresist in Nanoimprint Lithography Technology

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Abstract: Nanoimprinting technology (NIL) has received widespread attention due to its high precision and high efficiency in the preparation of micro and nanostructures. The key to NIL lies in selecting photoresist materials, with positive and negative photoresists being the main choices. This article aims to comprehensively analyze the advantages and limitations of positive and negative photoresists in NIL, with a focus on performance comparison and scalability for large-scale production. By conducting in-depth research on their properties and applications, this study aims to provide new references for the selection criteria of photoresists in NIL processes. Both positive and negative photoresists have certain advantages and limitations in NIL. Positive photoresist has high resolution and low surface tension, making it suitable for preparing high-precision micro/nanostructures. However, the development process of photoresist is relatively complex, requiring the use of development solution and a longer development time. In addition, the adhesion of positive photoresist to negatively charged surfaces is poor, which may lead to mold detachment or damage. Negative photoresist has high contrast and short development time, making it suitable for large-scale production and high-throughput preparation. The development process of negative photoresist is relatively simple, requiring only the use of developing solution and a shorter development time. However, the resolution of negative photoresist is relatively low and not suitable for preparing high-precision micro/nanostructures. Meanwhile, the surface tension of negative photoresist is relatively high, which may cause the mold to detach or be damaged. This article selects suitable positive or negative photoresists based on their specific application requirements in terms of resolution, surface tension, complexity of development process, and production scale, in order to achieve the best microstructure preparation effect.

Keywords: Positive Photoresist; Negative Photoresist; Nanoimprint Lithography; Mass Production

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1 Introduction

With the continuous development of nanotechnology, nanoimprint lithography (NIL) [1-5] has attracted widespread attention and research as a key technology for efficiently preparing micro and nanostructures. At the nanoscale, the preparation of microstructures is of great significance for various fields such as optoelectronics, nanoelectronics, and biomedicine. In NIL technology, the selection of photoresist materials is crucial for achieving

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precise micro/nanostructures, as they directly affect the scalability of the preparation process.

Nanoimprinting technology (NIL), positive photoresist [6] and negative photoresist [7] are two commonly used photoresist materials, which have different characteristics and applications in the preparation of micro and nanostructures [7-10].

Positive photoresist is a photosensitive material that undergoes chemical reactions when exposed to ultraviolet light, causing the photoresist molecules in the irradiated area to crosslink or break, thereby altering their physical properties. During the development process, the photoresist in the illuminated area is more easily dissolved in the development solution, forming the desired pattern. Positive photoresist is suitable for preparing patterns that match templates, such as in the preparation of microelectronic devices.

Negative photoresist has the opposite characteristics. When exposed to ultraviolet light, the molecules of negative photoresist undergo cross-linking, making the photoresist in the irradiated area less soluble in the developing solution. During the development process, the photoresist in the unexposed area will be dissolved, forming the desired reverse pattern. Negative photoresist is suitable for preparing reverse patterns, such as microlens arrays or optical waveguides.

The choice of positive or negative photoresist depends on the required pattern type and preparation requirements. Positive photoresist typically has higher resolution and longer development time, making it suitable for the preparation of micro/nanostructures that require high precision. Negative photoresist typically has lower resolution and shorter development time, making it suitable for faster preparation processes. In addition to positive photoresist and negative photoresist, there are other types of photoresist materials to choose from, such as double-layer photoresist and mixed photoresist. These different types of photoresist materials have their own characteristics and applications in NIL, and the most suitable materials can be selected according to specific needs [11-14].

In summary, positive photoresist and negative photoresist are commonly used photoresist materials in NIL, and they have different characteristics and applications in the preparation of micro and nano structures. Choosing the appropriate photoresist material can achieve high-precision and high-efficiency preparation of micro/nanostructures.

In this article, we will focus on comparing the advantages and limitations of positive photoresists and negative photoresists in NIL. Positive photoresist typically has the advantages of high resolution, simplified processing, and compatibility with standard lithography processes, while negative photoresist performs excellently in high contrast, superior etching resistance, and pattern design flexibility. We will conduct an in-depth comparison of their performance and explore their differences in scalability for mass production.

By comparing and analyzing these two types of photoresist materials, we aim to provide important references for the optimization and application of nanoimprint lithography technology, and promote the efficient preparation and application of micro nano structures. This is of great significance for promoting the development of nanotechnology in various fields, and is expected to open up new possibilities for future scientific research and engineering applications.

2 The Process of Nanoimprint Lithography

Nanoimprint lithography technology is a remarkable method for preparing micro and nanostructures, based on the principles of physical pressure and UV curing. The key steps of this technology include: 1. selecting a suitable graphics substrate; 2. Coating liquid silicone onto the graphic substrate; 3. Peel off the silicone gel after curing; 4. Contact the lithography template with the photoresist and apply a certain amount of pressure to fill the photoresist into the micro nano structure of the template; 5. Harden the photoresist through UV curing and heating methods; 6. By separating the template from the photoresist, a micro nano pattern that replicates the template structure can be obtained. The specific operation process is shown in Figure 1.

Compared to traditional lithography technology, nanoimprint lithography technology has multiple significant advantages [15-16]. Nanoimprinting technology is not limited by the resolution of photoresist. Due to the limitations of its composition and characteristics, traditional lithography techniques often face the problem of limited resolution when preparing micro nano structures. Nanoimprinting lithography technology can bypass the resolution limitations of the photoresist itself and effectively replicate high-resolution micro nano patterns by achieving direct physical pressure transfer.

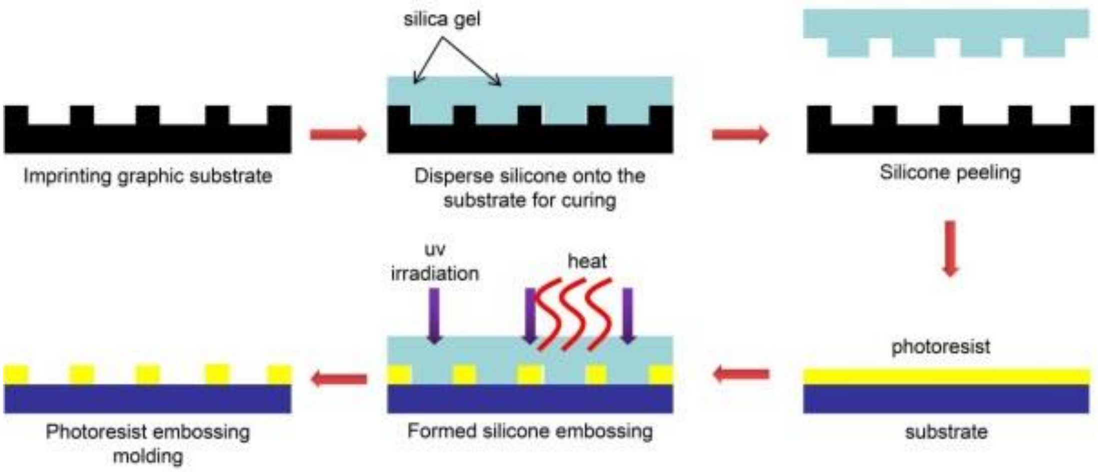

Figure 1 Schematic diagram of nanoimprinting process

3 Positive Photoresist

In nanoimprinting lithography technology, positive photoresist plays a crucial role. Its characteristics make it an ideal choice for preparing precision micro nano structures. The photochemical properties of positive photoresist result in chemical changes under illumination, leading to changes in the material properties of the irradiated area and making it more easily soluble in the developing solution. This characteristic makes positive photoresist suitable for preparing patterns with complex and fine features, which are often difficult to achieve through other preparation methods, the structures shown in Figure 2 are typical of these systems [17].

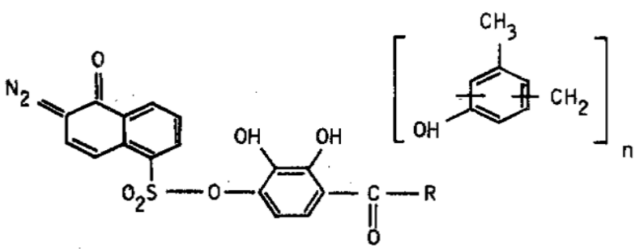

Figure 2 Chemical structure of a typical positive photoresist

Positive photoresist is known for its excellent resolution. Due to its chemical changes that enable highly precise pattern definition, positive photoresists are typically able to prepare structures with extremely fine features, thereby achieving high-resolution patterns [18-20]. This makes positive photoresist have important application value in the preparation of nanoscale devices, optical components, and biosensors. Positive photoresist typically requires fewer processing steps compared to negative photoresist. This means that during the preparation process, positive photoresist can reduce processing complexity, shorten preparation time, and lower costs [21]. This is crucial for industrial applications as it improves preparation efficiency, reduces production costs, and promotes the commercial application of nanodevices.

Meanwhile, the compatibility between positive photoresist and standard lithography technology is another important advantage. Due to the widespread use of positive photoresists in conventional lithography processes, they can be seamlessly integrated into existing preparation workflows. This provides engineers and researchers with more flexibility and convenience, enabling them to utilize existing equipment and processes for the preparation and research of micro nano structures.

In summary, positive photoresist is known for its high resolution, simplified processing, and compatibility with standard lithography techniques, and is an indispensable and important component of nanoimprint lithography technology. Their advantages make them have broad application prospects in various fields and provide strong support for the development and application of nanotechnology.

4 Negative Photoresist

The characteristics and advantages of negative photoresist make it an ideal choice for preparing complex micro and nanostructures. The main function of negative photoresist is to become less soluble in the developing solution under illumination, thereby preserving the irradiated area. This characteristic makes negative photoresist suitable for creating reverse patterns, and compared to positive photoresist, the patterns formed are the reverse of the illuminated area, the structures shown in Figure 3 are typical of these systems [22].

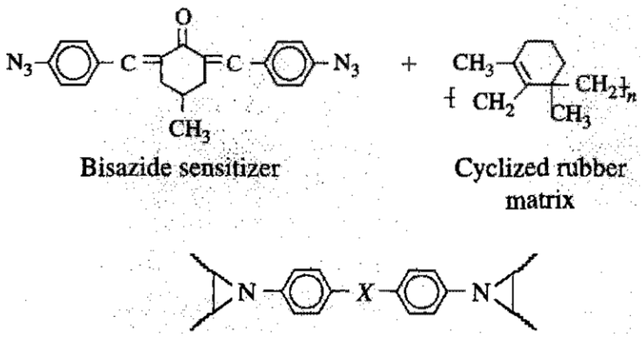

Figure 3 Chemical structure of a typical negative photoresist

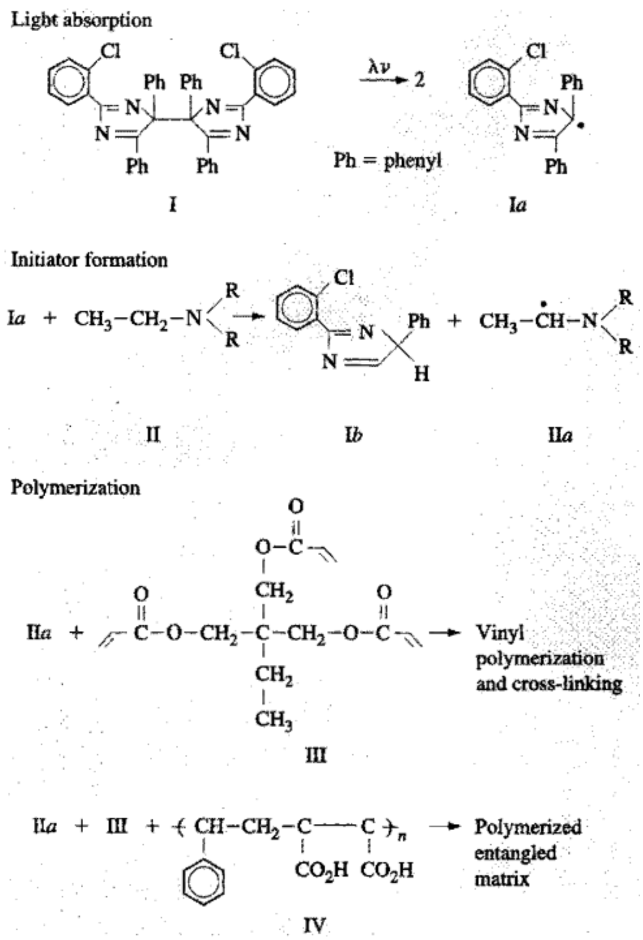

Figure 4 Schematic diagram of negative photoresist photochemical reaction under illumination

Negative photoresist has the advantage of high contrast. In negative lithography, the contrast between the illuminated and non illuminated areas is usually high, forming a pattern with clear edges [23]. This enables a more accurate definition of the required structure during the preparation process, improving the accuracy and controllability of the preparation, shown in Figure 4 [22]. Another advantage is that negative photoresists typically have superior etching resistance. Due to the unique properties of their materials, negative photoresists typically exhibit better resistance during the etching process, making them suitable for applications that require strong material properties [24-26]. For example, when preparing micro and nano devices, negative photoresist can better protect the required structure from damage when deep etching or high temperature resistance is required.

In addition, negative photoresist also has the flexibility of pattern design. Due to its ability to produce features smaller than the original mask size, it has greater flexibility and freedom in pattern design. This enables engineers and researchers to design more complex and refined structures to meet the needs of different application fields.

The cost of negative photoresist is usually lower, which is also one of its advantages. Compared to positive photoresist, the preparation process of negative photoresist is usually simpler and the material cost is lower, thereby reducing the preparation cost. This gives negative photoresist a greater competitive advantage in large-scale preparation and cost sensitive projects.

Negative photoresist is highly favored in the field of nanomanufacturing due to its high contrast, superior etching resistance, flexibility in pattern design, and lower cost. Its advantages make it an important tool for preparing complex micro nano structures and play an important role in various application fields.

5 Performance Comparison

In nanoimprint lithography technology, positive photoresist and negative photoresist each have their own characteristics and exhibit different advantages in performance, making them suitable for different types of application scenarios [27]. Positive photoresist is known for its excellent resolution and compatibility with standard lithography processes. Positive photoresist stands out in applications that require high-resolution patterns, enabling precise preparation of small features while maintaining good pattern fidelity. This makes positive photoresist particularly suitable for devices, optical components, and biomedical sensors that require highly refined preparation. Its compatibility with standard lithography processes further expands its application range, allowing engineers and researchers to efficiently prepare using existing equipment and processes.

Negative photoresist exhibits superior etching resistance and pattern design flexibility. Negative photoresists usually have better etching resistance and can maintain the integrity of the pattern during the etching process, making them important in applications that require high temperature resistance or deep etching. In addition, the pattern design flexibility of negative photoresist enables it to prepare various complex structures, including subtle features at the micro and nano scales. This makes negative photoresist play an irreplaceable role in applications that require strong material properties and complex designs, such as the preparation of microelectronic and optical devices.

Positive photoresist and negative photoresist each have their unique advantages and applicability. Positive photoresist is suitable for applications that require high resolution and compatibility with standard lithography processes, while negative photoresist has advantages in etching resistance and pattern design flexibility, making it suitable for applications that require strong material properties and complex designs. Therefore, when selecting photoresist, it is necessary to comprehensively consider its performance characteristics based on specific preparation requirements and expected application scenarios, in order to achieve the best preparation effect.

6 Mass Production Analysis

When considering mass production, positive photoresist and negative photoresist each have their own advantages and applicability, which need to be comprehensively considered based on specific preparation requirements and expected application scenarios.

Positive photoresist has significant advantages in mass production due to its simplified processing requirements and compatibility with existing preparation infrastructure. It can efficiently achieve high-resolution pattern preparation, usually requiring fewer processing steps, which can shorten the preparation cycle and reduce preparation costs. Compatible with existing standard lithography processes, positive photoresist can be easily integrated into existing preparation workflows, providing convenience and efficiency for large-scale manufacturing.

Negative photoresist also has indispensable advantages in certain specific applications that require superior etching resistance and pattern design flexibility. In these applications, such as those that require high temperature resistance or deep etching, negative photoresist can better protect the pattern structure and achieve more flexible and complex designs. Its low cost is also an important advantage, and it has a competitive advantage in some cost sensitive projects. Currently, nanoimprint lithography has achieved mass production in the field of patterned sapphire substrates, with negative photoresist being the main type of photoresist used. The imprint photoresist column is shown in Figure 5.

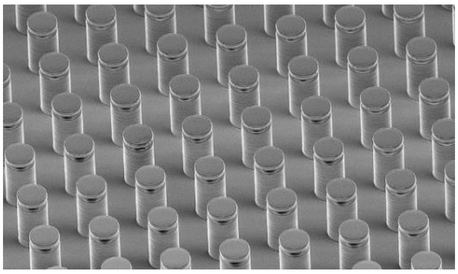

Figure 5 SEM images of nanoimprinted photoresist columns

When considering mass production, it is necessary to comprehensively consider the performance characteristics, cost, and compatibility with existing process equipment of positive and negative photoresists. Choosing the appropriate type of photoresist for different preparation needs and market positioning will have a significant impact on production efficiency and product quality. In practical applications, it may be necessary to adopt mixed use or targeted selection based on specific situations to maximize the advantages of lithography technology and achieve successful mass production.

7 Conclusion

The choice of positive or negative photoresist in nanoimprint lithography depends on the specific requirements of the preparation process and the expected application. Positive photoresist is suitable for high-resolution pattern preparation and process simplification, and is very suitable for mass production scenarios. On the contrary, negative photoresist provides unique advantages in etching resistance and pattern design flexibility, meeting specific application requirements that require strong material properties and complex designs. More importantly, negative photoresist has lower material costs and is more conducive to commercialization. A deep understanding of the properties and performance characteristics of each type of photoresist is crucial for optimizing the nanoimprint lithography process and achieving the desired preparation results.

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