Photo-curable Resin for UV-Nanoimprint Technology

Nobuji Sakai

Nanotechnology Group, New Business Development Department, Toyo Gosei Co., LTD., 4-2-1 Wakahagi, Inba-mura, Inba, Chiba 270-1609, Japan

This paper reviews and discusses photo-curable resin for UV nanoimprint. The resins had been offered a variety of curing systems and evaluated their characteristics for each application. Improvement of material technology is indispensable for the progress of UV nanoimprint technology. In particular, the release properties are important where the studies are continued for further improvement.

Keyword: UV-nanoimprint, UV-NIL, photo-curable resin, mold, radical polymerization, release agent, adhesive force, etching, electro deposition

1. Introduction

Nanoimprinting is a technology used for the molding process, where resin is placed between the mold and the substrate, and a nanometer scale pattern is transferred onto the resin. Chou et al. were the first to propose the technology in 1995, and it is gaining attention as a promising means of nanoeengineering. Compared with other nanoeengineering techniques, nanoimprinting only requires simple apparatuses and offers sufficiently high throughput, helping to realize low-cost nanofabrication. Chou’s method is called thermal nanoimprinting because thermoplastic resin is used as the material onto which images are transferred [1, 2, 3]. After this was developed, Haiisma et al. proposed another type of technology that uses photo-curable resin as the material onto which the images are transferred [4]. Nanoimprinting that uses photo-curable resin is called UV nanoimprinting. Fujimori et al. proposed an idea very similar to nanoimprinting as early as the 1970s [5, 6], and discussed both thermal and UV nanoimprinting techniques. Therefore, some observe that they were the first to suggest these techniques.

Fluidity of the material onto which the images are transferred greatly influences the processing time, because the nanoimprinting technique is a molding process technology. In UV nanoimprinting, to use low-viscosity photo-curable resin can reduce the processing time, and is best suited for use in mass production. Its transfer accuracy is excellent because it is a room temperature process and does not require a thermal cycle. Figure 1 shows the UV nanoimprinting process. In the first step, the substrate is coated with photo-curable resin. Second, a mold with a nanosized pattern is pressed onto the photo-curable resin. Then, UV light is passed through the mold or substrate to cure the photo-curable resin. Finally, the mold is peeled off of the resin. Note that there is a residual layer in the concave portions of the

(1) Coating
(2) Press
(3) UV exposure
(4) Demolding

Figure 1. UV-NIL Process
Increasingly, efforts are being made in many institutions to apply the technique to the processes for semiconductor devices [7, 8, 9, 10], storage media [11, 12], optical devices [13], and functional films [14, 15]. On the other hand, for the technology to become commercially viable, many technical issues are still being addressed in terms of the fabrication of nanoscale molds, mold durability, mold cost, removability of the mold from cured resin, the solid state properties of the resin on which the pattern is to be transferred, imprint uniformity, alignment accuracy, test techniques and applications [16, 17]. Among them, developmental studies are also being conducted on liquid photo-curable resin (which will simply be called resin hereafter) to be used as the material on which the pattern is transferred. This paper reports on aspects of the development of resin and studies on the evaluation of the properties of curable resin.

2. Photo-curable Resin for UV nanoimprinting

Liquid photo-curable resin is used as UV-NIL resin. Liquid photo-curable resin is a type of resin that changes from liquid to solid by the activity of light. This change occurs by the polymerization reaction of monomer (oligomer) constituents in the resin. In this process, a photo polymerization initiator activates polymerization. The initiator efficiently absorbs energy from a specific wavelength of the light from the optical source, and generates cure initiation materials. Resin is classified according to the polymerization system into several types: radical polymerization type, ion polymerization type, ene-thiol type, etc. Each type has its own material and curing properties, and it is desirable that the resin be chosen considering both the requirements of the application and the merits of the resin. The properties of resin with different types of curing mechanisms and developmental examples will be described in the following.

2.1. Free radical polymerization resin

Free radical polymerization resin contains a monomer or oligomer with vinyl or (meta-) acryl, which enables radical polymerization, as well as an initiator of photo-initiated radical polymerization (Fig. 3). There are two initiator types for photo-initiated radical polymerization: the cleavage type and the hydrogen abstraction type. The merit of using radical polymerization resin is its higher cure rate and the availability of a variety of materials. The necessary cure time is less than several seconds for the thickness range from several tens of nanometers to several tens of microns, although the exact timing depends on the light intensity and the thickness. Since most of acryl vinyl monomers can be used for this type of resin, it is possible to control the solid-state properties of the resin relatively easily, and this type of resin is used in many applications. The drawbacks are cure inhibition due to oxygen, volume contraction during the cure[18], and relatively poor heat-resistance properties.

![Figure 2. Application field of nanoimprint technology](image-url)

![Figure 3. Polymerizable compound and photo initiator for radical polymerization type](image-url)
material is successfully improved. It is reported that the improved mechanical strength contributes to the suppression of transfer failures.

2.2. Cationic polymerization resin

Cationic polymerization resin is a material containing a monomer or oligomer with cationic polymerization capability, such as epoxy or vinyl ether compounds, and a cationic photo polymerization initiator (Fig. 4). The cationic photo polymerization initiator is mainly a photo-acid generating agent: aromatic sulfonium salt or aromatic iodonium salt. Compared with radical polymerization resin, this type of resin is less susceptible to cure inhibition due to oxygen. Volume contraction is small, and the heat-resisting properties are excellent. Its disadvantages are slow cure, a narrow range of material choice, susceptibility to temperature and humidity during the cure, and limited applications because of the acid that remains in the system.

Figure 4. Polymerizable compound and photo initiator for cationic polymerization type.

Three examples of UV-NIL cationic polymerization resin will be described. First, the authors made and compared acryl radical polymerization resin and epoxy cationic curable resin [21]. The results of thermogravimetric (TG) analysis show the improved heat-resisting properties of the cationic polymerization resin. By using an organic-inorganic hybrid type epoxy cationic curable resin, the temperature of 5% weight loss is increased from 270°C for radical polymerization resin to 340°C.

Ito et al. reported on the development of cationic curable resin using a vinyl ether compound [22, 23]. The vinyl ether compound is characterized by low viscosity compared with other types of monomer, and the photo-curable resin using this material also shows low viscosity [24]. The authors achieved the transfer of 50 nm L/S using this resin. They further show that vinyl ether containing silicon is also applicable to UV-NIL if materials are properly selected. Iyoshi et al. reported on mold release using a hybrid resin of cationic and radical polymerization types. In this report, it is shown that the sensitivity is improved by optimizing the composition, and the mold removability is improved by suitably selecting the release agent [25].

2.3. Ene-thiol type resin

Ene-thiol type resin is optically cured by step reactions between a compound (ene) with two or more double bonds in the molecule and another compound with two or more thiols in the molecule. The reacting species are radical, but the cure inhibition by oxygen is less obvious compared with other known types of radical polymerization resin, as the thiyl radical that is produced is active and can react with inactive peroxy radicals. Another merit of step polymerization is that the material does not shrink too much. The drawbacks are that a variety of materials is not available and that thiols are odorous, although less odorous thiols are being developed. This type of material has not yet been extensively studied as the UV-NIL resin [26], but development is expected in the future.

2.4. Silicon-containing resin

We can expect a broader process window from the use of a multi-step etching process. The multi-step etching process uses a multi-layer structure of resin materials. Fig. 5 shows the process. There is a report, for example, where a silicon-containing material is used as the upper layer of the photo-curable resin in the bi-layer structure [20]. Silicon adds tolerability to oxygen dry etching. The tolerability to dry etching increases with the silicon content, and so the choice of monomer is important.

2.5. Fluorine-containing resin

When resin with high fluorine content is cured, its surface energy becomes small and it has excellent releasability. It is found that the contact angle of water on the cured surface of photocurable resin comprising a fluorine-containing monomer exceeds 90° [27]. Further, it is suggested that thermoplastic fluorine-containing polymer can be used as molding material for UV nanoimprinting.

2.6. Removable resin

A difficult part of nanoimprinting is in the
removal of resin, which tends to adhere to the mold. Wet-type removal is almost impossible because a cross-linking agent is added to the photo-curable resin to ensure the mechanical strength required in the release process. A possible solution for this problem would be to embed a structure in the polymerized resin that allows for chemical decomposition. For example, by emulating the design of the chemical amplification resist, it is proposed to use a monomer containing the t-butyl ester group and ketal group, which are dissociated under the presence of acid [28].

The multi-step etching process by using bi-layer structure of Si containing resin and transfer layer.

Figure 5. The multi-step etching process by using bi-layer structure of Si containing resin and transfer layer.

The design of Removable resin systems

Figure 7. The design of Removable resin systems

3. Characterization

Requirements for photo-curable resin are classified into two categories: basic process characteristics that are independent of applications, the application–oriented characteristics. When materials are developed, it is important to improve their characteristics, of course, but we must also develop the techniques of characterization.

3.1. Basic process characterization

Techniques for basic resin process characterization will be described. The basic process characteristics of UV-NIL resin are needed to ensure the throughput of the imprint process. They include coating properties, viscosity, releasing properties, mechanical strength, resolution, reproducibility, and photosensitivity (reaction rate, extent of polymerization). Here, we discuss releasing properties, transfer reproducibility, mechanical strength and the conversion rate.

3.1.1. Releasing properties

In the releasing process of UV-NIL, there is a type of failure in which the resin pattern is damaged [29] because resin tends to adhere to and may not be separable from the mold. For this reason, a release-promoting treatment is usually applied to the mold in advance. In the case of a quartz mold, for example, the mold surface is usually water-repellent finished using a silane coupling-agent of the perfluoroalkyl group [30, 31]. The greatest practical problem in the releasing process is the level of release enhancing capability and its stability [21, 32].

First, I describe reports on the effect of releasing treatment [21]. Taniguchi and the authors fabricated a sample and a jig for the measurement, as shown in Figs. 9 and 10, measured the stress needed for separating two slide glass plates, and studied the effect of the releasing agent. The adhesive force is measured using PAK-01. The releasing agent for UV-NIL is Optool DSX (Daikin Industries, Ltd.) and is diluted in a solvent to 0.05-0.2% by weight; dipping is used as the release treatment. The measurement result is shown in

Figure 8. Demand characteristics for UV-NIL resin

Figure 6. Replica method by using fluorine-containing polymer.

Figure 9. Demand characteristics for UV-NIL resin
Table 1. It is confirmed that the adhesive force is greatly reduced by the agent at any level of dilution, showing that the releasing treatment makes the releasing easy. Note that there are fewer flake failures when the difference is greater between the adhesive force between mold and resin and the adhesive force between resin and substrate. As compared to the case of untreated glass plates, which can be taken as representing the untreated case of adhesion between substrate and resin, the adhesive force of the treated mold is about ten times greater. This gives a sufficiently great contrast.

![Figure 9](image-url) Experimental setup of sample for the measurement.

![Figure 10](image-url) Experimental setup of the measurement of adhesive force and durability.

Table 1. Measurement Results of Adhesive Force of PAK-01.

<table>
<thead>
<tr>
<th>Release agent</th>
<th>Optool 0.05%</th>
<th>Optool 0.1%</th>
<th>Optool 0.2%</th>
<th>Not</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean value(MPa)</td>
<td>0.053</td>
<td>0.053</td>
<td>0.060</td>
<td>0.83</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.019</td>
<td>0.023</td>
<td>0.020</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Second, reports on the stability of releasing treatment will be described. Many reports show that the effectiveness of the releasing treatment gradually degrades as nanoimprinting is repeated [33, 34]. For example, Houle et al. find that the degradation of the effectiveness of the releasing treatment depends on the properties of the photo-curable resin [33]. However, note that the degradation still occurs, regardless of whether the resin is superior or inferior. It is proposed that a metal thin film over the silane coupling agent can be a promising releasing agent, as discussed earlier. Tada et al. studied the degradation in the releasing process using an X-ray analysis technique [34]. They found that the mixture ratio of the elements changes in the releasing agent and the thickness decreases as the imprinting is repeated, and found experimentally that the radical supplied from the photo-polymerization agent does not directly deteriorate the releasing agent. The mechanism of degradation of the releasing capability is not yet fully known, and remains an important technical subject in promoting the wide commercial use of nanoimprint technology.

In our experiment, the imprinting is repeated using a release-treated quartz mold, and we examined the relation between the adhesive force during the release process and the contact angle of water on the mold surface. A quartz plate is used as a mold with a transfer surface of 25 × 25 mm without patterns, and two types of samples, with and without release treatment, are prepared. In the releasing process, perfluorooctylethyltrichlorosilane (C8F17C2H4SiCl3, Glest) is used as a releasing agent in the vapor phase treatment (Fig. 11). The contact angle of water on the mold surface is found to be 40° without treatment and 80° with release treatment. Using these types of molds, the imprinting is repeated using an imprint apparatus from Mitsui Denki Seiki. The process of the repeated imprinting will be explained next. Firstly, resin is spin-coated with a finished thickness of 200 nm on the silicon wafer substrate. Then, the mold is contacted with the resin film to apply pressure using the imprint apparatus. After the set
weight of 200 N is reached, resin is cured by UV irradiation (100 mJ/cm²), during which the weight is kept constant. The mold is released from the resin after the UV irradiation. Then, we check the resin residue on the mold, the adhesive force and the contact angle of water on the mold surface. The resin residue on the mold is visually checked, and the contact angle of water is measured using a static contact angle meter. The adhesive force shows negative value in the earlier stage in the releasing process, and the value reduces to zero when the releasing process ends. The maximum value of the negative values was treated as the adhesive force. The measurement result is summarized as follows. Some of the resin begins to be left on the untreated mold after imprinting has occurred several times, while resin residue is not observed in the release-treated mold. I now discuss the variation of adhesive force and of contact angle. Using photo-curable resin and the mold with the contact angle of 80°, Fig. 12 shows the variation of adhesive force and the contact angle up to the 1,000th transfer. The adhesive force of the resin remains invariant up to 1,000 transfers, and the resin does not anomalously stick to the mold. However, the contact angle on the mold decreases very slowly as the transfer is repeated, indicating that the variation of adhesive force does not equate with the variation of the contact angle.

The decrease of the contact angle probably occurs because a wider surface area of quartz is exposed owing to the decreasing amount of releasing agent on the mold surface. It appears necessary to discuss the releasing properties not only from the viewpoint of the contact angle and adhesive force, but also from several other viewpoints.

3.1.2. Adhesion to the substrate

In another type of failure in UV nanoimprinting, resin abnormally comes off the substrate or under-layer. This problem is handled not only by improving the release capability, but also by improving the adhesion properties between the resin and substrate. In relation to this, there is a report on the debris appearing in UV nanoimprinting, where six types of commercial resin and three types of substrates are cross-examined to see if there is debris [33]. Note that the affinity between the resin and substrate is closely related to failure with the appearance of debris.

3.1.3. Efficiency of conversion

Resin for UV-NIL is cured by UV irradiation. To improve productivity, it is desirable for the resin to be cured by a smallest amount of UV irradiation. The polymerization resin can be evaluated by monitoring the cure process either through the change of mechanical properties [37] or through chemical analyses [24, 33, 37]. The reaction rate is measured by using Fourier Transform Infrared Spectroscopy (FT-IR) in the chemical analyses of the polymerizable functional groups in the resin. The measurement method is as follows. In the FT-IR measurement, the resin sample on the silicon wafer is UV-irradiated with the optical intensity of 5 mW/cm². The change in the absorption intensity of polymerizable groups in resin (with peaks at 810 or 1630 cm⁻¹) is tracked in real time, and the conversion rate is calculated from the change. The equation for calculating the conversion is given by Eq. (1). By taking an arbitrary baseline at time t at the peak position of the polymerizable group, we define conversion 0% by the peak or the area before the irradiation, and define conversion 100% by the peak or area 0 as Fig. 13 shows. The extent of conversion at the time t is calculated by:

\[
\text{Conversion} = \frac{(A_o - A_t)}{A_o} \times 100, \quad (1)
\]

where \(A_o\) is the peak or the area before UV
Irradiation, and \( At \) is the peak or the area after the irradiation time \( t \).

![Figure 13. A method for estimation of reaction value.](image)

Figure 13. A method for estimation of reaction value.

Figure 14 shows the measurement result for the conversion of PAK-01. PAK-01 has a large initial reaction velocity and the saturated extent of conversion is as large as \( \approx 85\% \) for the exposure 5 mJ/cm\(^2\), and 90\% for 10 mJ/cm\(^2\). Since the polymerization of resin is greatly affected by the choice of monomer, oligomer, and photo-polymerization initiator, a measurement result like this can be used in the selection of materials.

![Figure 14. Measurement Result of Photo-curing rate of PAK-01.](image)

Figure 14. Measurement Result of Photo-curing rate of PAK-01.

3.1.4. Transfer accuracy

The transfer accuracy of UV-NIL is evaluated by comparing the pattern configurations in the mold and in the resin. While the resolution of optical lithography depends on the wavelength of the light source, the resolution of UV-NIL depends on the mold configuration.

There are various tests to evaluate resolution; I take up two of them here. First, studies on the minimum resolvable pattern size will be described [38, 39]. Hua et al. attempted to transfer a carbon nanotube configuration. First, the carbon nanotube configuration is transferred to the polydimethylsiloxane of thermal cure type. Then, it is imprinted onto photo-curable resin using the cured polydimethylsiloxane as the mold. As a result, a carbon nanotube configuration of 2.4 nm is successfully transferred to the photo-curable resin.

The author now discuss the technique of transfer accuracy evaluation where the difference in the configuration is compared between the mold and the resin [40, 41]. Hiroshima reported on the comparison of line edge roughness (LER) in the patterns of the mold (Fig. 15) and the transferred resin (Fig. 16) [41]. The SEM measurement gave an LER difference of 0.1–0.2 nm between the mold and the transferred patterns.

![Figure 15. SEM image of Si patterns fabricated by anisotropic wet etching.](image)

Figure 15. SEM image of Si patterns fabricated by anisotropic wet etching.

![Figure 16. SEM image of transferred PAK-01 patterns.](image)

Figure 16. SEM image of transferred PAK-01 patterns. Ti with a thickness of 10 nm was deposited for preventing charge up.

This value is excellent compared with those of other processing techniques, indicating that the resolution of nanoimprinting is surprisingly good.
While only a small number of reports are available on the relation between the resolution and the resin type, there are some reports on the relation between the resin type and the cure shrinkage [18].

3.1.5. Viscosity
Nanoimprinting is a molding process technology, and the viscosity of resin influences the processing time. Lowering the viscosity reduces the processing time, which is advantageous in industrial applications. The viscosity is \( \approx 1 \) mPa\( \cdot \)s to apply vinyl ether monomers and 3–4 mPa\( \cdot \)s for the acrylate monomer [24].

3.2. Application-oriented characterization
The characteristics of UV-NIL resin are important for achieving the best product functionality. While many good characteristics are required, note for example that the imprint process can be classified into two categories: the removal of resin residue in the concave portion of the imprint pattern may or may not be required, depending on the application. Applications where this is not required, which are energetically studied by making use of the nanostructure of the resin surface, include optical devices. Imprinting becomes easier if the residual layer thickness is greater, and a thickness of the order of microns is usually adopted. Since the cured resin remains in the device, its characteristics will greatly influence the device reliability. Therefore, the cured resin must have an excellent level of weather resistance. On the other hand, the former applications include those for lithography using such wet processing as dry etching, plating, and lift-off. In applications for lithography, complicated processes usually follow the imprinting, so the key to success is consistency with these subsequent processes. In particular, the residual thickness greatly affects the subsequent processes, and it is important that the resin film be uniform and as thin as possible [42].

3.2. Characterization of resin for permanent devices
Issues related to resin depend on the target device, and will include: resistance to climatic conditions, resistance to humidity, thermal properties, and optical properties (transparency, refractive index, etc.). There is a variety of device types, and it is supposed that unique approaches are individually pursued.

Studies on thermal properties and transparency will be described in the following. The nanopattern fabrication on flexible resin films will also be described.

3.2.1. Thermal properties
The thermal properties of resin are among the items that are very important when resin is used in permanent devices [21, 43, 44]. We evaluated the heat tolerance of cured resin using differential thermogravimetry [21]. The upper temperature limit is defined as the temperature that reduces the weight by 5%. The samples are acrylate resin, epoxy resin and organic-inorganic hybrid resin. The measurement apparatus is TG-DTA200S (Mac Science), and the temperature is increased by 10°C/min in nitrogen. The measurement shows that the upper temperature limit is \( \approx 270^\circ \)C for acrylate resin, and is also \( \approx 270^\circ \)C for alicyclic epoxy resin. It is postulated that the similar level of heat tolerance is probably observed because the alicyclic epoxy resin tested has ester binding in the molecule, just as acrylate resin does. On the other hand, in resin where the main constituent is novolac epoxy resin, which does not have ester binding, there is an improved upper temperature limit of 310°C, and further, the organic-inorganic hybrid resin gives an upper temperature limit as high as \( \approx 340^\circ \)C.

3.2.2. Transparency
Optical applications require that the cured resin be colorless and transparent. The coloring of cured resin is strongly related to the composition of the cured material, and a good result is obtained by carefully choosing monomers and photo-polymerization initiators that are not causative of coloring. It should be noted that impurities might cause coloring if they are present in the photo-polymerization initiator. Figure 17 shows the UV spectrum for the cured films of commercial UV nanoimprint resin (PAK-01, PAK-02, Toyo Gosei).
3.2.3. Example of processing

Roll-to-Roll (RTR) imprinting offers high speed, large area continuous transfer [45]. This technique is expected to be used extensively in future, especially for applications that demand low cost and high-volume production. In particular, applications for functional films for display are gaining attention. An example of continuous transfer using the RTR technique will be discussed in more detail. In my study, the roll type mold is fabricated by attaching electroformed Ni molds on a metal roll. Adhesive-treated PET films (Cosmoshine A4100, Toyobo) with width 21 cm and thickness 100 µm are used as the substrate. The RTR imprinting process is shown in Fig. 18. The transfer process is as follows. First, the film substrate is coated with PAK-02. Then, the coated resin and mold come into contact with each other, and the mold is filled up with resin to transfer the pattern. UV light is irradiated from the substrate side for photopolymerization, and then the film substrate is released. The above steps are continuously processed with a film feed speed of 6 m/min. Figure 19 shows the pattern transferred.

3.3. Applications for lithography
3.3.1. Resin for dry etching

Dry etching is widely used in the electronic, including the semiconductor, industry. It is contributing significantly to microfabrication, and is very attractive from the viewpoint of nanoimprinting technology. From the inception of nanoprinting, using the transferred resin pattern as a mask for dry etching has repeatedly been attempted. The requirement for photo-curable resin is tolerability against dry etching. This can be improved by properly choosing the correct monomers and oligomers for the resin. There is a report on a technique that is based on the improvement of the photo-resist technique with respect to tolerability against dry etching [46]. In this report, the Onishi parameter and ring parameter of the constituents of resin are discussed.

An improvement observed by the authors shall now be described [13]. We tested PAK-01 and a newly trial-manufactured resin, PAK-TR11. The result of dry etching using these is shown in Fig. 20. Due to the difference of the constituents, PAK-TR11 has twice the dry etching tolerability of...
PAK-01. To reduce the residual thickness, dilution with an organic solvent is used, and the thickness of resin after spin-coating and before curing is reduced to \( \approx 60 \) nm. The silicon wafer is processed using PAK-TR11 (Fig. 21). By coating the wafer with photo-curable resin, a nanopattern of resin is formed using UV-NIL. Then, the residue of the resin pattern is removed using oxygen dry etching, and the silicon wafer is etched with the remaining pattern as a mask. The silicon pattern obtained is shown in Fig. 22.

The use of a multilayer process is also actively being pursued [47]. The use of a multilayer reduces the effect of irregularity in the substrate, as well as reducing scattering in the residual film thickness. In semiconductor processes, where exact line width control is required [48], the use of a multilayer process will become the mainstream if UV-NIL is adopted.

3.3.2. Resin for wet processes

Plating, etching and lift-off are the main wet processes in the industry. Techniques to combine them with nanoprinting have not yet been published in abundance. An application for plating developed by the author will be described [12, 13]. In addition to the residual film thinness, an important item of characterization in the use of resin is tolerability in the plating solution. I tested PAK-TR21, in which the constituents are adjusted for improvement in this application, and found a great enhancement of the tolerability in the plating solution, such that there were no failures such as swelling and flaking. Figure 23 shows the external appearance while immersed in the plating solution.
Using PAK-TR21, metal nanopatterns are formed using electrolytic plating and UV-NIL. Figure 24 shows the process. First, photocoatable resin is coated on a silicon wafer, on which a conducting layer has been formed, and the resin nanopattern is formed by the UV-NIL process. Then, the residue of the resin pattern is removed by dry etching, as discussed in the dry etching section, so that the conducting layer is exposed. Lastly, using electrolytic plating, metal is plated onto the conducting layer to form a metal nanopattern. Figure 25 shows the metal pattern formed by the electrolytic plating technique, where the cobalt alloy is plated onto the openings of the resin and then the resin is removed. While other techniques use complicated processes or expensive apparatuses in forming alloy nanopatterns, the adoption of the UV-NIL technique makes the process relatively simple and easy.

4. Summary

Studies on photo-curable resin are being conducted along with the development of UV nanoimprint technology. Among the photo-curable resin materials, the mainstream is the photo radical polymerization type, but other types of material are increasingly being studied. The items that characterize the UV nanoimprint resin are generally classified into the two categories of basic process characteristics and application-oriented characteristics. The basic process characteristics are important in maintaining the high throughput of the imprint process; among them, some of the results are described, such as the release properties and the reaction rate. In particular, the release properties are important where the studies are continued for further improvement. The application-oriented characteristics are related to the functionality of the final products, and the requirements differ with products. Some of the results are described from studies on thermal properties, transparency, RTR transfer, dry etching, and plating.

There are many items that characterize resin. In addition to those discussed here, resistance to climate, refraction index, and other chemical and physical properties must also be improved. Improvement of material technology is indispensable for the progress of UV nanoimprint technology. Since many institutions are now actively making an effort to improve resin, it is expected that superior resins will be available in the near future.

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