Metal Liftoff Process using Solvent Soluble Resist by UV-NIL

Tomoki Nishino^{*}, Noriyoshi Fujii^{*}, Hiroto Miyake^{**}, Takao Yukawa^{**},
Junji Sakamoto^{*}, Ryosuke Suzuki^{*}, Hiroaki Kawata^{*} and Yoshihiko Hirai^{*}

^{*}Osaka Prefecture University

Department of Physics and Electronics Engineering, Graduate School of Engineering
1-1 Gakuen-cho, Naka-ku, Sakai, Osaka, 599-8531, Japan

^{**}Daisel Chemical Industries Ltd

Organic Chemical Products Company

1239, Shinzaike, Aboshi-ku, Himeji, Hyogo, 671-1283, Japan

Metal liftoff process has been demonstrated using solvent soluble UV curable resin by UV nanoimprint lithography. Fine pattern is fabricated by UV nanoimprint using NIAC702 resist (Daisel Chemical), which is dissolved into Cyclohexanone. After removing residual layer by plasma etching, Cr is deposited by electron beam sputtering and the resist is dissolved by Cyclohexanone. Using solvent soluble UV curable resin, Cr pattern is successfully transferred on the substrate by liftoff process.

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1. Introduction

Nanoimprint lithography [1] is widely used for various industrial applications for fine pattern transfer in cost effective. Optical devices is one of the most promising applications for nanoimprint lithography because the transferred structures work as functional optical devices without any additional processes such as optical gratings, anti-reflection structures, wave plates and etc. We demonstrated anti-reflection structure using novel nanoimprint process [2], high aspect ratio wave plate [3], and optical grating using glass material [4]. Those applications were mostly using polymer materials.

On the other hand, plasmon devices [5] are rising up for new optical functional devices using nano structured materials such as nano metal dot array or 3 dimensional fine metal structures. To fabricate plasmon devices, electron beam lithography is usually applied, however it is not cost effective process because it takes long exposure time.

Nanoimprint lithography has been achieved to fabricate metal patterns by direct imprinting to soft metals [6,7], however residual metal layers are remained, which are not suitable for plasmon

devices nor optical devices.

Fabrication of metal patterns using nanoimprint lithography was firstly successfully demonstrated by S. Chou using PMMA by thermal nanoimprint process [1]. In thermal nanoimprint process, we have variety choices of resist materials and they are easily applied for metal liftoff process because polymers for thermal nanoimprint process are mostly solution dissolvable materials.

On the contrary, UV nanoimprint process [8] has high throughput performance and is room temperature process. It is easy to handle the process, however UV curable resins are mostly insoluble after UV curing. To remove the cured resin, dry plasma etching is required, which is not applicable for liftoff process.

To dissolve the cured resin, multiple light exposure system has been proposed [9], however it is not suitable for conventional liftoff process. On the other hand, solvent soluble UV curable resin has been proposed [10], which is dissolved by organic solvent after UV curing.

In this paper, we newly propose metal liftoff process using solvent soluble resist by UV nanoimprint process.

2. Metal liftoff process

Figure 1 shows the proposed process for metal liftoff. We use solvent soluble resist NIAC702 (Daisel Chemical), which is acrylate based radical polymerization UV curable resin. The resin is dissolved by Cyclohexanone and spin coated on Si substrate by 2000-3000 rpm. The resist is baked under 55 °C for 1 min. The initial thickness of the resist is approximately 200-400nm. Next, quartz template, which contains various patterns, is pressed on to the resist under 1.8 MPa in pressure under vacuumed ambient and UV light is irradiated at 40mJ/cm² in power for 60 s. After releasing the template, the residual layer is removed by Inductive Coupled Plasma Reactive Ion Etching (ICP) using ULVAC NE-550 etching machine. The etching gas is O₂ mixed with Ar.

Next, Cr is deposited by electron beam spatter using in-house equipment for around 50-200nm in thickness. Finally, the resist is dissolved by Cyclohexanone and the Cr on the resist pattern is removed.

Figure 1. The proposed process for metal liftoff.

3. Experimental result

3.1 UV nanoimprint

Figure 2 shows typical experimental result for UV nanoimprint using NIAC 702 resist. Fine patterns are successfully fabricated on substrate without fatal defects. The residual layer thickness is around 200nm, which is removed before metal deposition by the following IPC etching.

a) Low magnification view

b) High magnification view

Figure 2. Cross Section view after UV nanoimprint.

3.2 Residual layer removal

Figure 3 shows typical result after removal of the residual resist layer by ICP etching. The residual layer is removed in anisotropically and the substrate is opened between the resist patterns. The pattern width is reduced in 40 nm during vertical etching over 200nm in depth. The side wall of the pattern may be etched around 20 nm in lateral direction, which is fairly good anisotropic etching for polymer material. The cross section profile of the resist is not sharpened undercut profile and it is afraid that the side wall of the resist is covered with Cr.

Figure 3. Cross Section view after residual layer removal by IPC etching

3.3 Metal liftoff

After deposition of Cr layer, the sample is dipped into Cyclohexanone for 15 min to remove the resist. Figure 4 shows typical result after dipping in Cyclohexanone.

a) Line patterns

b) Dot array patterns

Figure 4. Bird's eye view after Cyclohexanone dipping. (15 min dipping)

The Cr layer on the rest does not removed with the resist and still remained, however some cracks are observed on the Cr layer and also pattern edges.

To remove the underneath resist layer, extra dipping under ultrasonic vibration is carried out in Cyclohexanone for 15 min.

Figures 5 and 6 show the results of Cr liftoff after extra dissolving under ultrasonic vibration in solvent.

Fine Cr lines and dot array with 600nm in feature size are successfully transferred by liftoff process using solvent soluble UV resist, respectively. Under ultrasonic dipping, the solvent flow into the resist through the cracks and dissolved. As a result the Cr layers on the resist are successfully removed

As demonstrated above, Cr patterns are transferred by UV nanoimprint process using solvent soluble resist.

a) Low magnification view

b) High magnification view

Figure 5 Transferred Cr lines by liftoff process

a) Low magnification view

b) High magnification view

Figure 6. Transferred Cr dot array by liftoff process

4. Conclusion

Metal liftoff process using solvent soluble UV curable resin is newly proposed by UV nanoimprint process. Fine Cr line pattern and dot

array pattern are successfully demonstrated.

We believe liftoff process in combination with UV nanoimprint lithography is promising way to fabricate metal nano patterns for plasmon devices in cost effectively.

References

1. S. Chou, P. Krauss, and P. Renstrom, *Appl. Phys. Lett.* **67**, (1995) 3114.
2. K. Sogo, M. Nakajima and Y. Hirai, *J. Photopolym. Sci. Technol.*, **19**, (2006) 647.
3. T. Yoshikawa, T. Konishi, M. Nakajima, H.Kikuta, H. Kawata, and Y. Hirai, *J. Vac. Sci. Technol. B* **23**(2005) 2939.
4. Y. Hiraia, K. Kanakugi, T. Yamaguchi, K. Yao, S. Kitagawa, Y. Tanaka, *Microelectronic Engineering* **67–68** (2003) 237.
5. for example, H. Atwater, *Scientific American* (April 2007) 56.
6. S. Pang, T. Tamamura, N. Makao, A. Ozawa, and H. Masuda, *J. Vac. Sci. Technol.B*, **16** (1998) 1145.
7. Y. Hirai, T. Ushiro, T. Kanakugi, T. Matsuura, *Proc. of SPIE* **5220**, (2003) 74.
8. M. Colburn, S. Johnson, M. Stewart, S. Damle, T. Bailey, B. Choi, M. Wedlake, T. Michaelson, S.V. Sreenivasan, J. Ekerdt, and C.G. Willson: *Proc. of SPIE* **3676** (1999) 378.
9. D. Matsukawa, H. Wakayama, K. Mitsukura, H. Okamura, Y. Hirai and M. Shirai, *J. Mater. Chem.***19** (2009) 4085.
10. T. Yukawa, S. Iyoshi and H. Miyake, *Proc. Jpn. Soc. Appl. Phys. annual meeting* (2009, Tukuba) 30a-K- 9, in Japanese.