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Development of ordered nano structure surface by using nano plastic forming

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Abstract:

The authors propose a new nano fabrication process by using nano plastic forming in this paper. The proposed process consists of nano plastic forming, coating and polishing. In the first step, diamond tool is imprinted onto a soda glass substrate. And array of nano grooves are fabricated. Then, the fabricated glass is coated with nickel or aluminum by vapor deposition. Finally, the coated layer is removed by polishing. Through these processes, the array of metallic nano lines can be fabricated on the surface of glass substrate. In this study, the feasibility of the proposed process was confirmed by the experiment.

Keywords: Ordered nano structure surface, Nano plastic forming, Hard-brittle material, Vapor deposition, Polishing

1. Introduction

Ordered nano structure surface have important applications in the recent engineering fields such as bioengineering, opt-electrical engineering, material engineering and nano-mechanical engineering. For example, ordered quantum dots array presents unique characteristics such as quantum size effect and coulomb blockade [1]. They are useful for developing new semiconductors for quantum dot laser [2] and quantum computer. Metal nanodot array is expected as substitution of the flash memory because of its advanced information retention. Nano hole array can constitute photonic crystals [3]. They can control light freely because of its photonic band gap. So, they are expected to use as optical devices in the next generation. Also, nano dot or line array is useful for biosensing devices such as DNA chips or protein chips and biosensing chip by using phenomenon of surface plasmon resonance [4]. These devices are expected to develop medical care.

These micro structures on the surface of a material are usually fabricated by Photo Lithography(PL) and Ultra Violet Lithography(UVL). These techniques are capable of fabricating hard-brittle materials such as glass and silicon, and are advantageous for mass production. These fabrication techniques however have limitations in the size of fabricating due to exposure wavelength. In recent years, new lithography techniques such as Electron Beam Lithography(EBL) and Extreme Ultra Violet Lithography(EUVL) [5] were developed to realize miniaturization of structure size. However, equipment costs of them are extremely expensive. Also, these methods are disadvantageous to environment due to usage of hazardous chemicals.

Recent years, nano imprint lithography(NIL) was developed to address problems of throughput and cost. In NIL process, a nanostructured mold is imprinted onto polymers.

However, NIL has restriction in work materials and

degree of freedom in geometry. Accordingly, development of low-cost and less stringent nano fabrication process is desired.

In this paper, a new nano fabrication process is proposed. This process is based on plastic forming method in nano meter scale, which method is named Nano Plastic Forming(NPF). It is shown that a ordered nano structure is fabricated on the surface of a glass by combination of NPF, vapor deposition and polishing process. Through these experiments, the feasibility of the proposed process was confirmed.

2. Experimental procedure

Figure 1 illustrates a new nanofabrication process proposed in this paper. The proposed process is separated into three steps; NPF, coating and polishing.

Firstly in this process, diamond tool is imprinted onto a soda glass substrate. In this study, a knife edge type tool is applied, because it is easy to fabricate arbitrary shape on the work material by using this tool. The knife edge type

Figure 1: New nanofabrication process by using NPF

tool is imprinted onto a soda glass substrate, and array of nano grooves are fabricated. NPF is the same as plastic forming in principle.

Then, the fabricated glass is coated with nickel or aluminum by vapor deposition. The nanostructures of nano grooves are filled with the coated metal.

Finally, the work material is polished and its metal on the surface of the work material is removed. The coated metal is inlaid in the nano grooves.

3. Results and discussion

3.1 NPF process

Figure 2 shows a NPF device used for the experiments. It has computer controlled X-Y stages and a Z stage. Resolution of those stages is 10 nm, and the stroke of X-Y stages is 20 mm whereas for Z stage, the stroke is of 40 nm. A tool and a load cell are mounted on the Z stage. The X-Y axis stage is mounted on a tilt stage, whose resolution is 0.015 degrees. The load cell measures the indentation load. The complete process of imprinting involving the movement of stages and imprinting load are controlled by a computer. NPF is conducted inside a clean booth so that effect of dust is avoided.

Figure 3 shows a knife edge type tool used for the experiment. This is made of a single crystal diamond. The edge angle of the knife edge tool is 60 degrees, and the width is 0.6 mm. Its edge was ground to very sharp and the edge radius was less than 50 nm. This diamond tool was provided by Tokyo Diamond Tools MFG. Co., LTD.

Nano groove arrays were fabricated on the surface of soda glass substrate to examine feasibility of NPF. In the experiment, the knife edge type tool was indented on a glass substrate. Indentation load was tested between 1.0-3.5 N, and the pitch was between 0.5-2.0 μm . Nano groove arrays were fabricated in the area of 0.6 mm $\times$ 0.6

Figure 2: Photograph of NPF device

Figure 3: Knife edge type tool

mm.

The relationship between the load and the depth or the width of indented groove were evaluated from the SIM photographs.

Figure 4 shows relationship between indentation load and the indentation depth. It is found from Fig. 4 that the indentation depth is proportional to the indentation load.

Figure 5 shows relationship between indentation load and the indentation width. It is found from Fig. 5 that the indentation width is proportional to the indentation load. However, the indentation width is about 3.5 times larger than the indentation depth. Under normal circumstances, the indentation width is about 1.2 times larger than the indentation depth because the edge angle of the knife edge tool is 60 degrees. This is caused by tool wear. Appropriate management of tool is necessary in the future work.

Figure 6 shows example of SEM micrographs and AFM images of nano grooves. (a) is a nano groove array. Indentation load was 2.0 N and pitch was 1 μm . (b) is a nano groove lattice. Indentation load was 2.0 N and pitch was 1 μm . In both cases, nano groove arrays were fabricated in the area of 1.2 mm $\times$ 1.2 mm. It is observed in the SEM micrographs and the AFM images that grooves were formed uniformly and no cracks were generated around the grooves. This is because the soda glass can be fabricated in ductile manner when the indentation depth is less than the critical depth [6]. Width of grooves is about 350 nm, and depth is about 50 nm.

According to these results, depth and width can be controlled by indentation load. Also, many patterns can be

Figure 4: Relationship between indentation load and the indentation depth

Figure 5: Relationship between indentation load and the indentation width

Figure 6: SEM micrographs and AFM images of ordered nano structures fabricated by using the knife edge type tool

made at arbitrary position on a substrate by modifying the control program.

3.2 Coating process

The soda glass substrate was coated with aluminum or nickel by vapor deposition. The temperature of the surface of the specimen was 360-450 K when aluminum was coated. In case of nickel, the temperature of the surface of specimen was 410-510 K. These conditions were controlled by changing the distance from the source to the surface of specimen or current of heater. The deposition time of aluminum was 3-6 min and of nickel was 5-10 min. Thickness of the coated layer is 80-150 nm.

3.3 Polishing process

The soda glass substrate coated with metal was polished with diamond slurry. Particle diameter of the slurry is 1 μm .

The adhesion of metal layer and glass substrate depends on the temperature of the specimen during vapor deposition. Therefore, in order to study the effect of temperatures on adhesion of metal layer, the polishing process was tested using different coating temperatures. In these experiments, the soda glass substrate was coated with aluminum under the following conditions: temperature of the surface of the specimen was 340 K, 370 K, 390 K or 420 K. In case of 340 K, the coated aluminum layer was easily peeled off during polishing. On the other hand, in case of 420 K, coated aluminum layer remained not only in nano grooves but also on the surface of glass after polishing. The coated aluminum layer was inlaid only in the nano grooves under the following conditions: the temperature was 370 K or 390 K. According to these results, optimized condition of the temperature of the surface of the specimen during vapor deposition of aluminum was determined to be 370-390 K. In the same way, optimized condition of nickel was determined to be 460-480 K.

Figure 7: Ordered nano structure surface fabricated by using NPF

Under these conditions, coated metal was polished. The polishing depth was controlled by polishing time and polishing load. By the trial-and-error method, the optimized polishing condition was determined to be 10-25 min and 0.036 MPa.

3.4 Fabrication of ordered nano structure surface

Figure 7 shows SEM micrographs of various ordered nano structure surface fabricated by using NPF. (a) is a array of aluminum lines fabricated on a soda glass. Nano grooves were fabricated by using the knife edge type tool in the area of 1.2 mm $\times$ 1.2 mm on the glass substrate. Indentation load was 2.3 N and pitch was 1 μm . Then, the glass substrate was coated with aluminum with optimized condition of vapor deposition. Thickness of the coated layer was 150 nm. Then, the coated aluminum layer was removed with diamond slurry. Aluminum line width is about 500 nm. (b) is a array of nickel lines fabricated on a soda glass substrate by the same process as (a). Indentation load is 1.3 N, pitch is 500 nm and line width is about 150 nm. (c) is also a array of nickel lines. Indentation load is 2.0 N, pitch is 2 μm and line width is about 400 nm. (d) is a lattice of nickel lines. Indentation load is 2.0 N, pitch is 1 μm and line width is about 250 nm.

Figure 8: Relationship between indentation load and the Al line width

Figure 9: Relationship between indentation load and the Ni line width

In order to confirm the controllability of metal line width, array of metal lines was fabricated on the condition that indentation load was 1.3-2.5 N, pitch was $2\mu\text{m}$ and fabricated area was $0.6\text{ mm} \times 0.6\text{ mm}$. Figure 8 shows relationship between indentation load and the aluminum line width. It is found from figure 4 that the aluminum is proportional to the indentation load. Figure 9 shows relationship between indentation load and the nickel line width. According to these results, width of metal line can be controlled by NPF load.

(a) EDS analysis of Al linear array

(b) EDS analysis of Ni linear array

Figure 10: SEM micrographs and EDS line analysis results of nano line array

It was confirmed by using EDS analysis that metal was inlaid in the grooves. Figure 10 shows SEM micrographs and EDS linear analysis results of nano line array. (a) is a EDS linear analysis result of aluminum line array. The linear analysis was carried out along the line AA'. (b) is a EDS linear analysis result of nickel line array. The linear analysis was carried out along the line BB'. It is found from Fig. 10 (a) that aluminum was inlaid in the grooves. However, small amount of residual aluminum was observed on the surface of the flat part of the glass. Optimization of polishing condition is necessary in the future work. It is found from Fig. 10 (b) that nickel was inlaid only in the grooves.

In this process, arbitrary ordered nano structure such as pith, pattern and width can be made by controlling NPF load or programs. Also, various materials are available in this process.

4. Conclusion

In this study, a new nano fabrication process by using nano plastic forming was proposed. The feasibility of the proposed process was confirmed by the experiment.

- (1) Various kind of ordered nano structures were fabricated by using plastic forming on hard-brittle materials such as soda glass. Proposed process is available to various kind of substrates.
- (2) It was shown that the new process is more advantageous than conventional lithography processes, because it was simple in process, less stringency and lower equipment cost.
- (3) Various ordered nano structure surface such as series of array of metallic lines and lattice of metallic lines can be fabricated by the proposed process by controlling the NPF load and the programs.

References

- [1] Yu, L.W. Chen, K.J.; Song, J.; Wang, J.M.; Xu, J.; Li, W.; Huang, X.F. Source: Thin Solid Films, v 515, n 13, p 5466-5470, May 7, 2007
- [2] Bhattacharya, P. Mi, Z.; Yang, J.; Basu, D.; Saha, D. Source: Journal of Crystal Growth, v 311, n 7, p 1625-1631, March 15, 2009
- [3] Gibson, B.C. Huntington, S.T.; Rubanov, S.; Olivero, P.; Digweed-Lyytikäinen, K.; Canning, J.; Love, J.D. Source: Optics Express, v 13, n 22, p 9023-9028, October 31, 2005
- [4] Matsushita, Tomohiko Nishikawa, Takeo; Yamashita, Hideyuki; Hasui, Ryosuke; Fujita, Satoshi; Okuno, Yutaro Source: Japanese Journal of Applied Physics, Part 1: Regular Papers and Short Notes and Review Papers, v 47, n 9 PART 1, p 7420-7427, September 12, 2008
- [5] Theodore E. Faradzhev, Nadir S. Yakshinskiy, Boris V.; Edwards, N.V. Source: Applied Surface Science, v 253, n 4, p 1691-1708, December 15, 2006
- [6] M Yoshino, S Aravindan, Y Kinouchi and T Matsumura, Journal of Advanced Mechanical Design, Systems, and manufacturing, 2, 1 (2008), pp. 59-70