Paper:

# A Uniform Pressure Apparatus for Micro/Nanoimprint Lithography Equipment

**Jian-Shian Lin*,**, Chieh-Lung Lai*, Ya-Chun Tu*, Cheng-Hua Wu*, and Yoshimi Takeuchi****

*Mechanical and System Research Laboratories, Industrial Technology Research Institute
195 Chung Hsing Rd., Sec.4 Chu Tung, HsinChu, Taiwan 310, R.O.C.
E-mail: johnnylin900698@gmail.com
**Department of Mechanical Engineering, Osaka University
2-1 Yamadaoka, Suita, Osaka 565-0871, Japan
[Received September 17, 2008; accepted November 6, 2008]

**Nanoimprint lithography (NIL) has overcome the limitation of light diffraction. It is capable of printing features less than 10nm in size with high lithographic resolution, high manufacturing speed, and low production cost. The uniformity of pressure, however, remains a critical issue. To improve the uniformity of pressure, we developed a flexible uniform pressure component based on Pascal's Law. When external force is applied to this component, uniform pressure is delivered to the mold and substrate. Average pressure over the embossed area using our improved nanoimprint equipment deviates by only 3.15%.**

**Keywords:** nanoimprint, uniform pressure, lithography

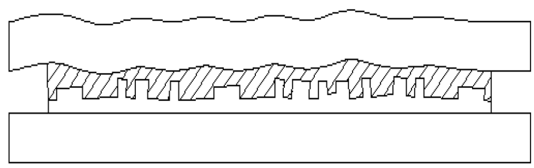

**Fig. 1.** Uneven imprinting.

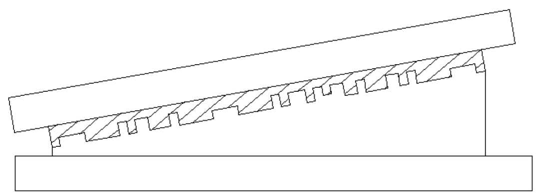

**Fig. 2.** Nonparallel imprinting.

## 1. Background

### 1.1. Technical Introduction

Nanoimprint lithography (NIL) involves pressing a nanomold mechanically under high temperature and pressure to duplicate nanostructures on a substrate to which polymer photoresist is applied. Processing resolution is limited by the critical mold size [1–4].

### 1.2. Critical Development

Since the introduction of NIL in 1995, many innovative nanoimprint researches have been done [5] using mold imprinting in which lithographic resolution reached 5 nm [6]. Due to uneven imprint (**Fig. 1**), molds or substrates may be bent or distorted – the major cause of asymmetrical imprinting depth, partial microstructure twisting, and deformation. Microstructures may also be damaged while the mold is being removed from the substrate when imprinting is uneven. If the mold and substrate do not remain parallel (**Fig. 2**), the microstructure angle differs at each imprinting, compromising quality and damaging nanostructures on the mold or substrate due to excessive inclination. Gao et al. have developed air cushion pressing (ACP) in which the mold and substrate are pressed together by gas pressure rather than a solid plate. Their method produces much more uniform measured pressure distribution than conventional hot embossing [7]. Jang et al. have designed fluid-based heating and pressing for hot microembossing, which makes heat and pressure distributed over the embossed area more uniform than in conventional hot embossing, and fluid-heated hot embossing requires a much shorter cycle time [8, 9].

## 2. Uniform Pressure Apparatus Design

To solve these problems, we propose an innovative imprinting control using a uniform pressure apparatus that precisely controls imprinting depth and uniformity, thereby improving imprinting quality (**Fig. 3**).

Our design is based on Pascal's Law – that is, pressure is equal at any point within an enclosed space filled with hydrostatic fluid – and uses a flexible uniform fluid-filled pressure element (**Fig. 4**). Exerting force on this element delivers uniform pressure to the mold and substrate (**Fig. 5**).

The nanoimprint equipment using the uniform pressure apparatus based on Pascal's Law consists of a cover, a closed end, a uniform pressure element, a first plate, a flange, a mold, forming materials, a substrate, and a second plate (**Fig. 6**). The cover is hollow inside with the open end having a flange. The top side of the first plate

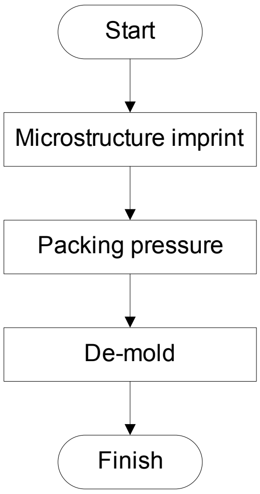


**Fig. 3.** Nanoimprint.

**Fig. 4.** Rubber bag.

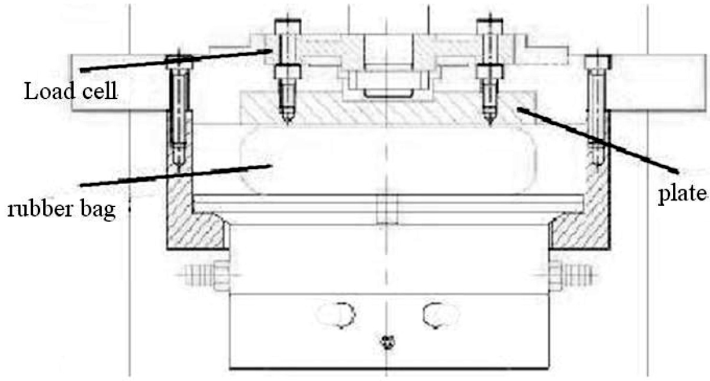


**Fig. 5.** Uniform pressure apparatus.

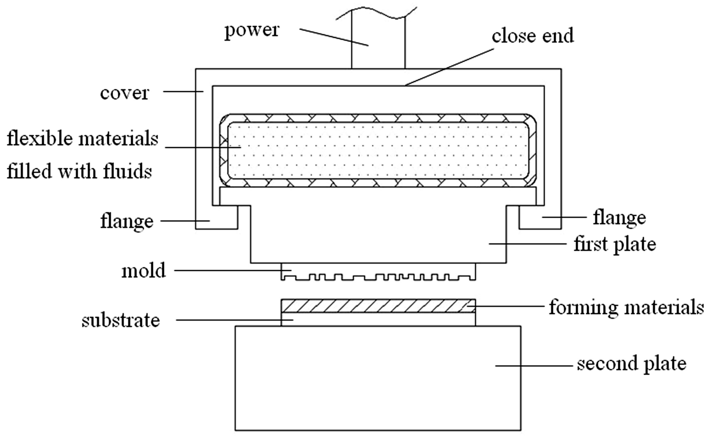


**Fig. 6.** Nanoimprint equipment.

has a flange larger than the opening end of the cover. This flange is embedded inside the cover so that the first plate is kept from falling off the cover. The first plate carries the nanostructure mold. The uniform pressure element, located above the first plate opposite to the mold, is made of flexible fluid-filled material. Fluid inside the element remains at a constant overall pressure so that the element simultaneously provides uniform pressure and parallel distance between the mold and substrate. The second plate holds the substrate with forming materials. A power source moves the cover and first plate toward the second plate, providing the force during imprinting (**Fig. 7**).

In imprinting (**Fig. 7a**), the substrate is positioned in advance together with the mold. Power is turned on (**Fig. 7b**) and the cover, first plate, and mold are driven toward the substrate on the second plate so that the mold directly contacts the substrate parallel to it. The cover moves toward the uniform pressure element after the first plate leaves the cover with the flange, and the closed end of the cover eventually contacts the uniform pressure element. Force consistently exerted on the cover is transferred to the uniform pressure element (**Fig. 7c**), compressing the element to distribute all required imprinting force at the designated value. The power source then moves in reverse to remove the closed end of the cover away from the uniform pressure element and leads the mold off the substrate to complete imprinting (**Figs. 7d** and **8**).

## 3. Nanoimprint Experiments

To confirm the influence of the uniform pressure element on imprinting, we conduct experiments using a polished silicon wafer for both the mold and substrate. We insert pressure-measurement film (Prescale, Fujifilm) between the mold and substrate to directly measure imprint pressure distribution. When the power source transmits force, the flexible uniform pressure element distributes pressure evenly to the mold and substrate via hydraulic pressure. After imprinting ends, microcapsules on the pressure-measurement film are broken and coloring materials inside the capsule react with color-development materials. The number of broken microcapsules in a given area is directly proportional to the pressure exerted, so pressure distribution is presented as fading color. We then use a concentration meter and a pressure converter to quantify pressure distribution and to analyze its uniformity.

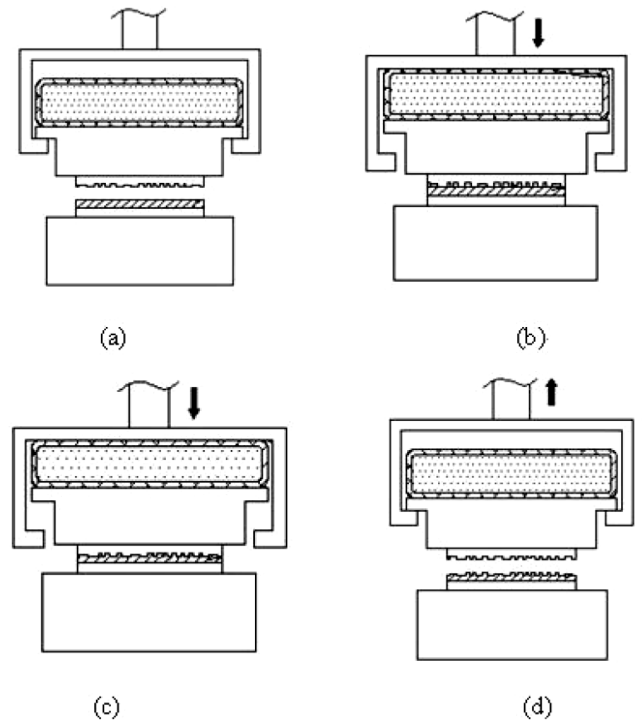


**Fig. 7.** Nanoimprint process.

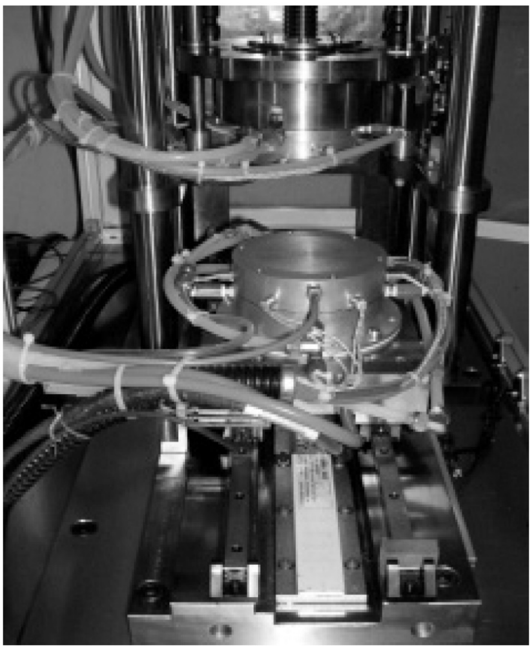

**Fig. 8.** Uniform pressure nanoimprint apparatus.

### 3.1. Results of Conventional Hot Embossing Imprinting

Pressure distribution in conventional hot embossing shows that variations in color fading are large because most hot embossing equipment does not take pressure uniformity into account, with only the surface of the plates hosting the mold and substrate polished (**Fig. 9**). Plates used too long may also become partially deformed, making pressure uniformity unsatisfactory.

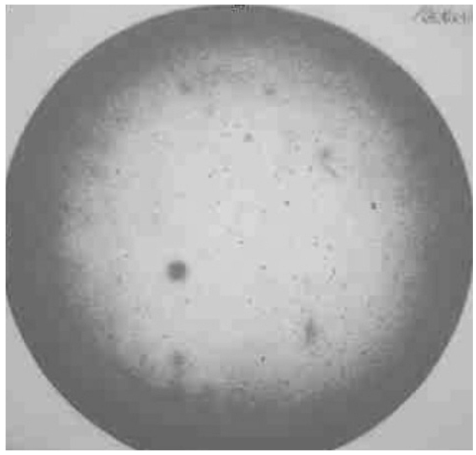

**Fig. 9.** Pressure distribution in conventional hot embossing.

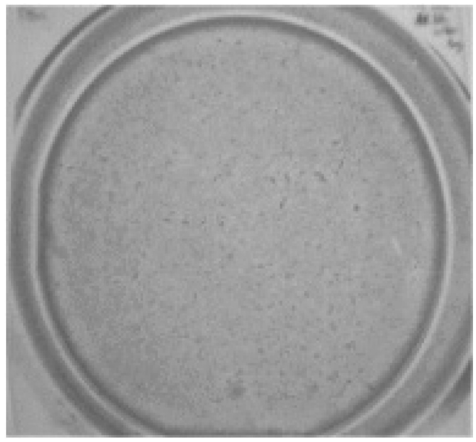

**Fig. 10.** Pressure distribution of hot embossing imprinting with uniform pressure apparatus.

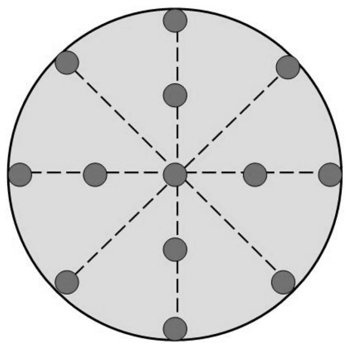

**Fig. 11.** Reference points.

### 3.2. Hot Embossing Imprinting with Uniform Pressure Apparatus

According to pressure distribution in hot embossing using our uniform pressure apparatus, we clearly observe that color fading varies less compared to conventional hot embossing (**Figs. 9** and **10**). The flexible uniform pressure element transmits uniform pressure directly via fluid. Even if equipment is used for a long time, pressure uniformity is maintained and plate bending presents no concern.

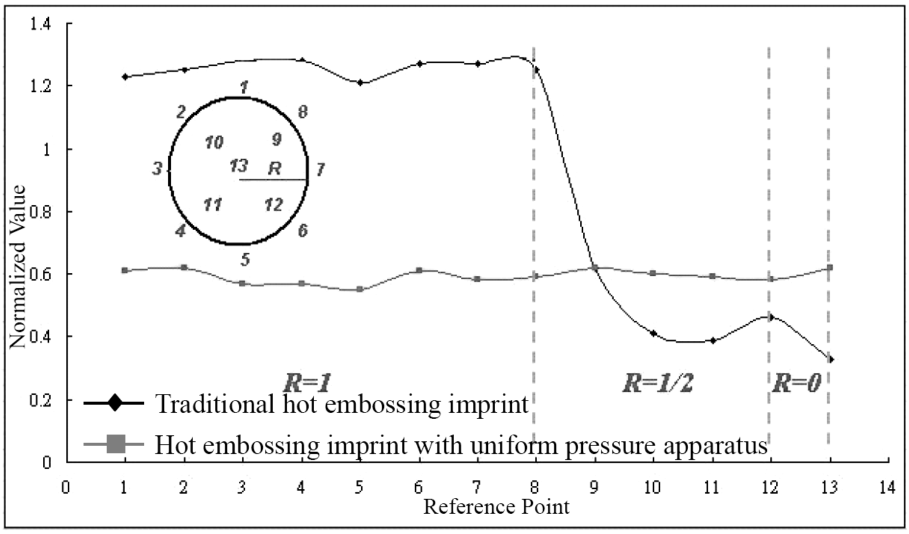


**Fig. 12.** Pressure quantification analysis.

### 3.3. Comparison of Results

We designate 13 locations as reference points on the pressure film (**Fig. 11**) and quantify them via the pressure converter as follows:

$$(\vec{E}) = \sum_{i=1}^{N} E_i \Big/ N, \quad E_i = x_i - \vec{x}/\vec{x}. \quad \ldots\ldots \quad (1)$$

$N$ denotes the sampling number; $x_i$ represents the pressure of point $i$; $\vec{x}$ is the mean pressure, and $E_i$ is the average deviation of point $i$ (**Fig. 12**). In conventional hot embossing, the pressure uniformity is unsatisfactory: peak pressure varies 4 times from $R = 1$ to $R = 0$ and deviation averages 40.84%. Using our uniform pressure apparatus, pressure variation is significantly reduced and average deviation is merely 3.15%.

## 4. Conclusions

We have proposed a uniform pressure design concept and demonstrated its feasibility through experiments. Imprinting resulting from the pressure-measurement film shows that the pressure uniformity of conventional hot embossing equipment is unsatisfactory, deviating at an average of up to 40.84%. The uniform pressure element we designed significantly improves pressure uniformity, reducing average deviation to just 3.15%.

**References:**

[1] S. Y. Chuo, P. R. Krauss, and P. J. Renstrom, "Imprint of sub-25nm vias and trenches in polymers," Applied Physics Letter, Vol.67, No.21, pp. 3114-3116, 1995.

[2] D. H. Raguin and G. Michael Morris, "Analysis of antireflection-structured surfaces with continuous one-dimensional surface profiles," Applied Optics, Vol.32, No.14, pp. 2582-2598, 1993.

[3] E. Noponen and J. Turunen, "Binary high-frequency-carrier diffractive optical elements: electromagnetic theory," Journal of the Optical Society of America A, Vol.11, No.3, pp. 1087-1096, 1994.

[4] S. S. Wang, R. Magnusson, J. S. Bagby, and M. G. Moharam, "Guided-mode resonances in planar dielectric-layer diffraction gratings," Journal of the Optical Society of America A, Vol.7, No.8, pp. 1470-1474, 1990.

[5] S. Y. Chou, P. K. Krauss, and P. J. Renstrom, "Nanoimprint lithography," American Vacuum Society, J. Vac. Sci. Technol. B, Vol.14, No.6, pp. 4129-4133, 1996.

[6] M. D. Austin, H. Ge, W. Wu, M. Li, Z. Yu, D. Wasserman, S. A. Lyon, and S. Y. Chou, "Fabrication of 5 nm linewidth and 14 nm pitch features by nanoimprint lithography," Applied Physics Letters, Vol.84, No.26, pp. 5299-5301, 2004.

[7] H. Gao, H. Tan, W. Zhang, K. Morton, and S. Y. Chou, "Air Cushion Press for Excellent Uniformity, High Yield, and Fast Nanoimprint Across a 100 mm Field," NANO LETTERS, Vol.6, No.11, pp. 2438-2441, 2006.

[8] J. H. Chang and S. Y. Yang, "Gas pressurized hot embossing for transcription of Micro-Feature," Microsystem Technologies, Vol.10, pp. 76-80, 2003.

[9] J. H. Chang and S. Y. Yang, "Development of fluid-based heating and pressing for micro hot embossing," Microsystem Technologies, Vol.11, pp. 396-403, 2005.

**Name:**
Jian-Shian Lin

**Affiliation:**
Manager, Lighting Module Technology Department, Advanced Manufacturing Core Technology Division, Industrial Technology Research Institute

**Address:**
Rm.118, Bldg.22, 195, Sec.4, Chung Hsing Rd. Chutung, Hsinchu, Taiwan 310, R.O.C.

**Brief Biographical History:**
2001- Yuan Ze University, College of Electrical Engineering
2001- Joined Industrial Technology Research Institute

**Main Works:**
• "Authentication labels based on guided-mode resonant filters," Optics Letter, Vol.32, pp. 1612-1614, 2007.

**Membership in Academic Societies:**
• Chinese Institute of Engineers
• The Illuminating Engineering Society of Taiwan (IEST)

**Name:**
Chieh-Lung Lai

**Affiliation:**
New Lighting Design Project Leader, Lighting Module Technology Department, Advanced Manufacturing Core Technology Division, Industrial Technology Research Institute

**Address:**
Rm.118, Bldg.22, 195, Sec.4, Chung Hsing Rd. Chutung, Hsinchu, Taiwan 310, R.O.C.

**Brief Biographical History:**
2004- Joined Industrial Technology Research Institute

**Main Works:**
• "A microstructure diffuser plate for LED lighting," SPIE Optical East, Vol.6758, pp. 1-10, Sep. 26, 2007.

**Name:**
Ya-Chun Tu

**Affiliation:**
Lighting Module Technology Department, Advanced Manufacturing Core Technology Division, Industrial Technology Research Institute

**Address:**
Rm.118, Bldg.22, 195, Sec.4, Chung Hsing Rd., Chutung, Hsinchu, Taiwan 31040, R.O.C.

**Brief Biographical History:**
2006- Lunghwa University of Science and Technology, Department of Mechanical Engineering
2008- Lunghwa University of Science and Technology, College of Engineering

**Main Works:**
• "Diffractive barcode using grating-dot lines," OPTICS LETTERS, Vol.33, No.17, September 1, 2008.

**Name:**
Cheng-Hua Wu

**Affiliation:**
Manager, Industrial Technology Research Institute

**Address:**
Rm.118, Bldg.22, 195, Sec.4, Chung Hsing Rd. Chutung, Hsinchu, Taiwan 310, R.O.C.

**Brief Biographical History:**
2008- Industrial Technology Research Institute

**Name:**
Yoshimi Takeuchi

**Affiliation:**
Dr. Eng., Professor, Department of Mechanical Engineering, Graduate School of Engineering, Osaka University

**Address:**
2-1 Yamadaoka, Suita, Osaka 565-0871, Japan

**Brief Biographical History:**
1971 Graduated from the University of Tokyo
1976 Graduated from the University of Tokyo, Doctor course
1978- Associate Professor, Kyushu Institute of Technology
1988- Professor, the University of Electro-Communications
2002- Professor, Osaka University

**Main Works:**
• "Ultraprecision Machining Center and Micromachining," Nikkankogyo Press Publisher, Jun., 1998.
• "5-axis Control Ultra-precision Machining of Complex-shaped Mirrors for Extreme Ultraviolet Lithography System," Annals of the CIRP, Vol.55, No.1, pp. 123-126, Aug., 2007.

**Membership in Academic Societies:**
• The International Academy for Production Engineering (CIRP)
• The Japan Society of Mechanical Engineers (JSME)
• The Japan Society for Precision Engineering (JSPE)