Fluorescence Alignment for Atomic-Scale Position Adjustment in Ultraviolet Nanoimprint Lithography

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Ultraviolet nanoimprint lithography (UV-NIL) has attracted much attention in nanolithography technologies because of low line edge roughness, high throughput and cost effectiveness.[1] The fabrication of electronic devices through UV-NIL often requires multiple pattern transfer. Thus, it is crucial to precisely detect misalignment between synthetic quartz mold and silicon substrate with alignment marks. The misalignment detection currently relies on analyses of multicative-type moiré fringes generated by superposition of a pair of bar-mark arrays with different periodicities in industry despite its high cost coming from additional optical function layers. This trend comes from the fact that the enlargement of the misalignment using the moiré fringes could complement a low resolution of imaging sensors at the time of the invention. Recent development of the imaging sensors allows easy detection of the position of a fluorescent single molecule at single-digit-nanometers by fluorescence microscopy. We have recently proposed fluorescence imprint alignment using fluorescent UV-curable liquids and the principle of additive-type moiré fringes.[2,3] We herein demonstrate, by simulation, that the misalignment could be detected at atomic-scale precision using fluorescence alignment without relying on the conventional moiré method.

Fluorescence model images consisting of four bar-mark arrays with two periodicities of p_1 and p_2 were produced using Adobe Photoshop (Details are shown in Figure 1). The misalignment (d) can be determined to be $d = (dx_1 - dx_2 + dx_3 - dx_4)/2$, where dx_i is a phase shift of the bar-mark array (i = 1-4) from the origin. After producing the images, the substrate was moved by a set value of d, and the fluorescence intensities (I_i) arising from the bar-mark arrays were analyzed by fitting using the following equation to determine each value of dx_i:

$$I_i = a_i \cos\left\{\frac{2\pi(x - dx_i)}{p_i \times q}\right\} + b_i$$

where $a_i/2$ is amplitude, x is analytical position, p_i is periodicity, q is correction value of magnification, b_i is intensity of base line. The analyzed d value includes a detected value of the real misalignment (d_r) and its standard error (Δd). Figure 2 shows the dependence of 8-bit and 12-bit gradations on standard error for detection of a misalignment of 5 nm when the periodicities of the array were analyzed. The increase in the gradation to 4096 (12 bit) achieved the detection of 5 nm with sub-nm precision. The standard error was less deviated by increasing the number of the period analyzed. These results suggest that the fluorescence imprint alignment can achieve the position adjustment with atomic-scale precision.

[1] K. Yamamoto *et al. Proc. SPIE* **11855**, 1185509 (2021). [2] E. Kikuchi, M. Nakagawa *et al. J. Vac. Sci. Technol. B*, **35**, 06G303(2017) [3] M. Nakagawa *et al. Jpn. J. Appl. Phys.* **59**, SIIJ11 (2020).

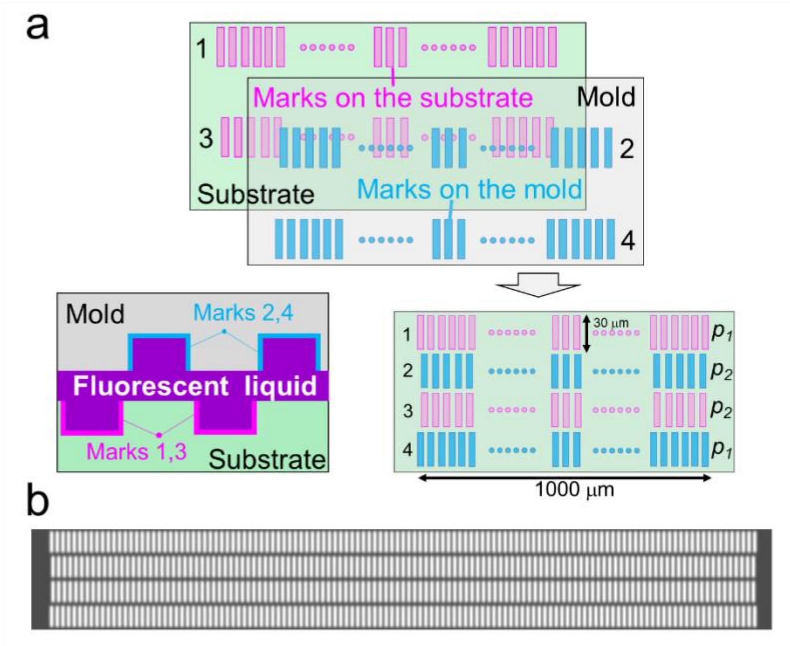

Figure 1: (a) Schematic illustrations of a mold and a substrate overlaid in ultraviolet nanoimprinting. The mold and substrate recesses of concave bar-mark arrays are filled with fluorescent UV-curable liquid. (b) Fluorescence model image of fluorescent UV-curable liquid sandwiched between the mold and the substrate surfaces produced by Adobe Photoshop: (a) The four bar-mark arrays are noted by the number of 1, 3 for a substrate and 2,4 for a mold. The pitches of the arrays 1, 4 and 2, 3 are denoted by p_1 and p_2, respectively. (b) The image was produced with p_1 = 8.1 μm and p_2 = 8.0 μm. The value of d was set to be 5 nm. The image of the bar-mark arrays was blurred using Gaussian blur with a blur radius of 1.78 μm to represent actual imaging. The image resolution for the fitting analysis was set to be 25400 ppi (1 pixel per 1 micron).

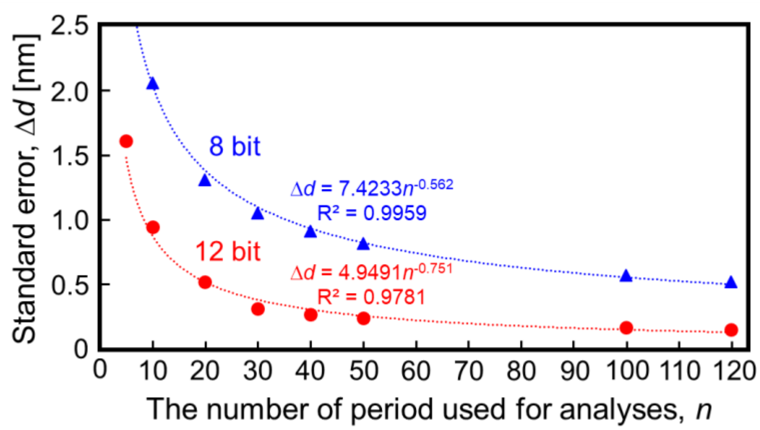

Figure 2: Dependency of standard error (Δd) of the real misalignment (d_r) on the number of period of the bar-mark arrays used for the analyses of a set value of 5 nm using 8 bit and 12 bit gradations: Dotted lines are the curves fitted by power functions.