

Nanoimprint process for arrayed waveguide grating patterns in silicon photonics

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Abstract

Imprinting lithography is a promising technology to make nanometer scale patterning possible with low processing price. In a decade, many researches think that polarisers, diffractive optical elements, self-cleaning surfaces, and photonic crystals will be the applications for the nanoimprint process. Silicon photonic which uses wave guides to deliver, merge, and distribute light signals is also an interesting research field which has high commercializing potential. The waveguides should be transparent in infrared light usually 850~1550nm range, and have a variety of patterns with different size and shape.

We use SU-8 photo resist for the waveguide material. The extinction coefficient of this material is almost zero over 400nm wavelength, and its refractive index is about 1.58 over 800nm wavelength. Moreover, it is possible to coat this material thick over 10um or thin less than 1um on a silicon substrate.

The imprinting tool we use is substrate conformal imprinting lithography. This technique is the most advanced nanoimprinting tool which ensures large area uniform imprinting. The key feature of this technique is to control the minute deformation of a thin but stiff replica mold using air pressure and vacuum. We improved this technique by adding dead-mode zone to block the air flow between the air and vacuum lines.

We applied our technique to make arrayed waveguide grating patterns for silicon photonic devices. The pattern size varies from 1um to hundreds of microns and its depth is about 3um scale. This pattern will deliver the infrared light emitting from VCSELs located beneath the patterns to photo sensors a few millimetres apart from it.

nanoimprint, silicon photonics, arrayed waveguide grating, substrate conformal imprinting lithography

1. Introduction

The nanoimprint lithography [1] can reduce many process steps into one to make patterns on semiconductor devices. This is the main strength of the nanoimprint lithography and its cost-down effect in production still attracts attentions of many researchers.

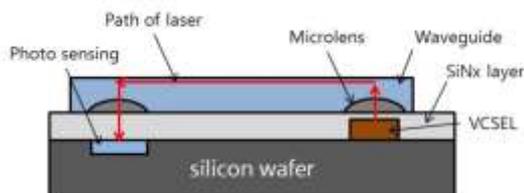


Figure 1. The conceptual design of silicon photonic devices.

Figure 1 shows the conceptual design of photonic devices which deliver information in the form of light signal instead of electric one [2]. The logic circuit not shown in figure 1 will be fabricated at the center of the chip and the VCSELs which emit light signal and photo sensors which receive light information will be placed at the peripheral region of a chip. The whole circuit region will be protected by dielectric passivation layer like silicon nitride. On top of this layer, optical components will be fabricated and guide the light signal among chips.

The optical components include arrayed waveguide grating (AWG), microlens, and optical waveguide. The process issue is how much we can save in fabrication of these components and

we believe the nanoimprint lithography is the best process to implement waveguide pattern.

2. Substrate conformal imprint lithography

The substrate conformal imprint lithography (SCIL) first released by Philips is the most advanced nanoimprint lithography, especially for large area ultraviolet nanoimprint research [3,4]. The key feature of SCIL process is the usage of a thin glass which has about 200um thickness for the substrate of a replicated mold. This glass substrate gives enough flexibility in out-of-plane for conformal contact and stiffness in in-plane to prevent shrinkage.

2.1. Flexible glass replica

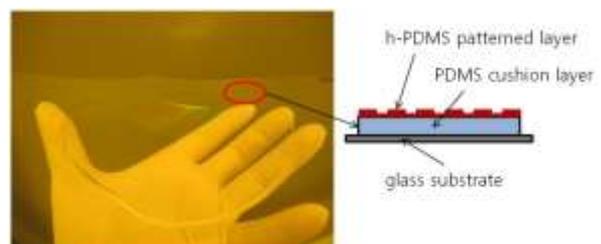


Figure 2. 3-layer flexible glass replica

Figure 2 shows the replica mold comprised of glass substrate as a backbone, polydimethylsiloxane (PDMS) as a cushion layer, and h-PDMS as a patterned layer [5]. We used 210um or 100um thin glass manufactured by Nippon Electric Glass Co.,

Ltd. Japan. The h-PDMS layer contains pattern which will be imprinted, and it is replicated from a silicon master. The PDMS layer with a 700um thickness acts as a cushion to compensate minute flatness error between mechanical surfaces to be contacted.

2.2. SCIL tool

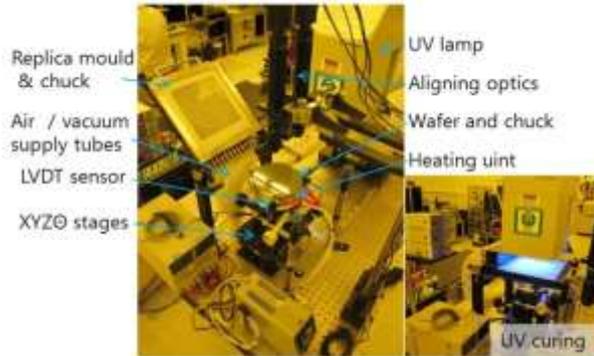


Figure 3. SCIL tool for 6-inch wafer process

Figure 3 shows the homemade SCIL tool specialized in 6-inch wafer process. The most important part is the replica mold chuck which controls the deformation of it using air pressure and vacuum. There are 76 furrows with 1.5mm width and 3mm pitch and each furrow is controlled individually by a controller. When air is supplied in a furrow, the mold surface which is in contact with it will be inflated in a micron scale. If air is supplied to more furrows nearby it, the inflated mold surface reaches in a contact point with a wafer surface. The SCIL tool has three LVDT sensors, so we can control the parallelism and elevation between the mold and a wafer surface in the range of 100~150um.

Air will be supplied to the furrows in one by one from a side of the chuck, and then the gradual inflation induced by this operation ensures conformal and defect free nanoimprint process.

2.3. Waveguide material

SU-8 is chosen for the waveguide structure in this research. The SU-8 purchased from MicroChem Corp. is transparent in infrared range and it has enough mobility to fill micron scale cavities in nanoimprint process.

The minimum feature in this research is 1um size in width and height, and the design thickness of residual layer after nanoimprinting is about 0.2~0.3um on top of silicon oxide passivation layer. To optimize the residual layer, the SU-8 resin is diluted with gamma butyrolactone (GBL) solvent, and its ratio is 1:0.6. After O₂ plasma treatment in 20 minutes, the diluted SU-8 is coated on a 6-inch silicon wafer with 3000rpm speed.

3. Experimental results

Figure 4 shows the experimental results for AWG pattern. Figure 4 (a) is the photograph of a demultiplexing (DEMUX) pattern over 100um size and waveguide lines with 1.7um width are connected at each side of the DEMUX (figure 4 (c)).

To fabricate this pattern, the air pressure supplied during nanoimprinting is 7kPa, and the SCIL controller opens furrows in series at every 1-second. After uniform contact, UV light exposes the assembly during 20 minutes. There is no post exposure baking (PEB) after detaching the mold from the

silicon wafer. Figure 4 (b) shows the fidelity of imprinted patterns and figure 4 (d) shows the pattern depth and the thickness of the residual layer.

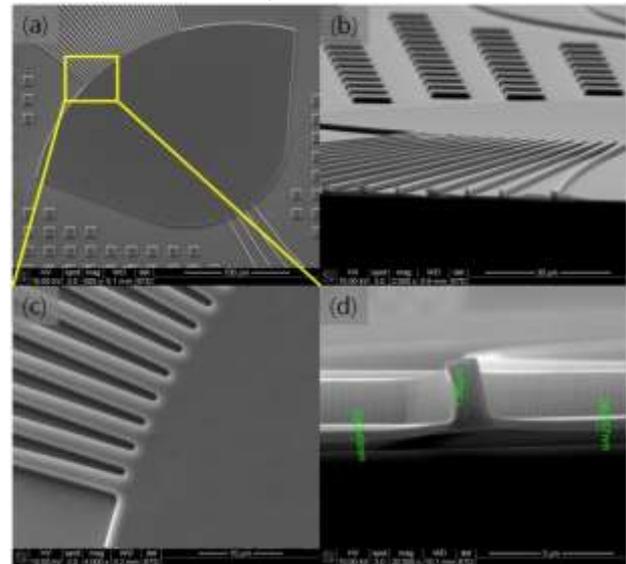


Figure 4. Photographs of imprinted AWG patterns.

4. Conclusions

This research shows one application of the SCIL process in silicon photonics. The AWG pattern is designed and fabricated using the commercialized SU-8 resist, and the process recipe for optical waveguide is proposed. In near future, nano- and micro hybrid patterns will be needed in photonic devices to manipulate optical path, and the nanoimprint including SCIL process will take place in related manufacturing fields.

Acknowledgements

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