Effects of phase shift mask design on three-dimension nanostructure fabrication

Nara Institute of Science and Technology, °Pongsakorn Sihapitak,
Yasuaki Ishikawa, Xudongfang Wang, Mutsunori Uenuma, and Yukiharu Uraoka
E-mail: yishikawa@ms.naist.jp

In recent years, there has been a lot of interest in high efficiency and flexible thermoelectric devices. One of the promising approaches toward the high-efficiency thermoelectric device is the use of a three-dimensional (3D) nanostructure. The porosity of the nanostructure will decrease the lattice thermal conductivity[1] which will increase the efficiency of the thermoelectric device. In order to obtain the nanostructure, there have been many options to fabricate the 3D nanostructure, such as the use of the vacuum process (chemical vapor deposition [CVD], the physical vapor deposition [PVD]) and non-vacuum process such as the proximity-field nanopatterning(PnP)[2]. By using the PnP process, 3D nanostructures can be achieved[3,4]. In this research, the phase shift mask, which can generate light diffraction, results in producing the periodic 3D nanostructure in the photoresist, has been studied. As to find a way to improve the efficiency of the thermoelectric device, we investigate the relationship of the nanostructure size and the improvement of the thermoelectric properties. In this study, we investigate the size limitation of the nanostructure of that the PnP process can fabricate.

RSOFT simulation software was used to study different phase shift mask dimensions (periodicity, width, height) and how it affects the nanostructure dimensions (the SU-8 pillars [SU-8 is the negative photoresist]) during the PnP process. It is important to note that, when performing the simulation, an important parameter (filling factor [FF]) needs to be considered. The FF needs to be ~50% for all of the new phase shift mask designs because the FF of the phase shift mask design will result in an optimized intensity generated in the photoresist[3]. Finally, the simulation parameters used are: laser wavelength 0.355 μm, the refractive index of SU-8 1.66, the refractive index of the PDMS phase shift mask 1.4.

The results show that the decrease in the size of the nanostructure can be achieved by changing the periodicity in the simulation in this case from the periodicity 0.6 μm to 0.3 μm successfully, as shown in Fig. 1. However, the size of the nanostructure cannot be decreased, or it will cause the percentage of unexposed parts per all areas in the photoresist to be reduced. This percentage is important because it will contribute to the porosity of the nanostructure, which will increase the efficiency of thermoelectric devices. As for periodicity 0.28 μm of the phase shift mask, this parameter is not considered for the phase shift mask designs due to the percentage of the unexposed part per all area is significantly lower compared to the periodicity 0.3 μm, as shown in Fig. 2. Note that all of the parameters of the mask design have an FF of 50%. Also, due to the size of the holes, the fabrication will be more challenging to achieve. To summarize it is implied that the periodicity 0.3 μm is the limiting size for the PnP process performed by the simulation. Finally, actual PnP fabrication can proceed after making a phase shift mask with the above-mentioned parameters as the next step of this research.

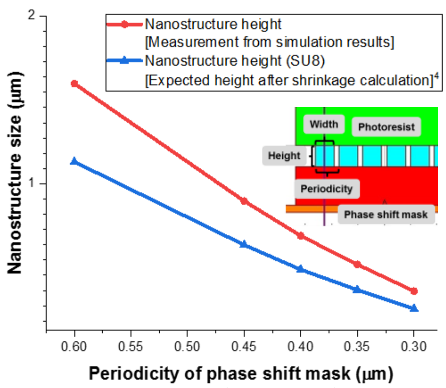

Figure 1. The periodicity of the phase shift mask and the size of nanostructure[4].

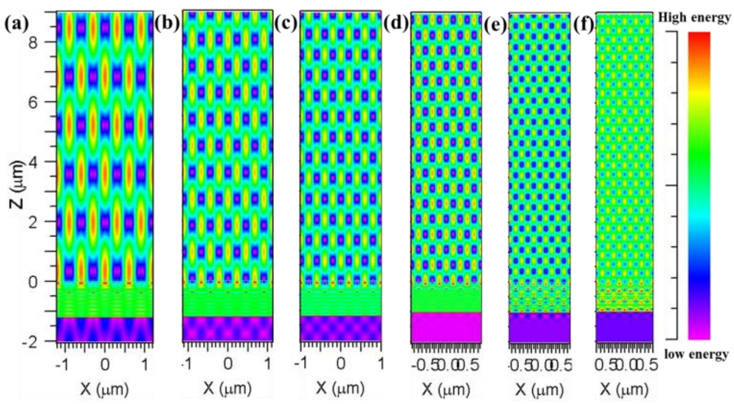

Figure 2. Simulation results (a) periodicity 0.6 μm (b) periodicity 0.45 μm (c) periodicity 0.4 μm (d) periodicity 0.35 μm (e) periodicity 0.3 μm (f) periodicity 0.28 μm.

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