Evaluation of Nanoimprint Lithography as a Fabrication Process of Phase-shifted Diffraction Gratings of Distributed Feedback Laser Diodes

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We have studied nanoimprint lithography (NIL) for fabricating diffraction gratings of distributed feedback laser diodes (DFB LDs). NIL is an attractive method since it takes shorter time to form phase-shifted gratings compared with electron beam lithography (EBL). However, it should be considered that compound semiconductor substrates used for DFB LDs have large undulation affecting the uniformity of residual layer thickness. We also focus on characteristics and reliabilities of LDs because the substrates are easily damaged by mechanical stress during imprint process.

DFB LDs having diffraction gratings with the period from 200 to 250 nm have been formed on a 2-inch InP wafer with epitaxial layers. We used the S-FIL/R process offered by Molecular Imprints, Inc.[1] After imprinting, spin-coating of Si-containing resin is followed by etch-back to reveal the tops of the imprinted corrugations. Next, the revealed layer is selectively etched through to the substrate, and the formed patterns are used as masks for the subsequent etching in order to transfer the patterns to the substrate. After that, a conventional buried-heterostructure process was used to fabricate DFB LDs.[2]

Figure 1 shows distributions of photoluminescence (PL) intensity of the epitaxial layer before and after imprint. No significant change in PL intensity is seen after imprint, indicating the epitaxial layer suffers no damage by imprint pressure. Figure 2 is a bird's-eye photograph of an imprinted substrate. It shows high uniformity in residual layer thickness, though it is affected by undulation of the substrate. Figure 3 is an oscillation spectrum of a $\lambda/4$ phase-shifted LD, which evidently shows the peak wavelength corresponds to Bragg wavelength. It demonstrates that NIL is comparable to conventional EBL as a fabrication process of phase-shifted LDs. Figure 4 shows the time-dependent change in operation current of LDs with the output power of 10 mW at the ambient temperature of 85ºC. No significant change has been seen in operation current up to at least 5000 hours, indicating the LDs have high reliability.

These results show that nanoimprint lithography has a high potential for the fabrication of diffraction gratings of DFB LDs.

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[1] M. Miller *et al.*, Proc. SPIE 5751 (2005) 994
[2] H. Ichikawa *et al.*, Jpn. J. Appl. Phys. 47 (2008) 7890

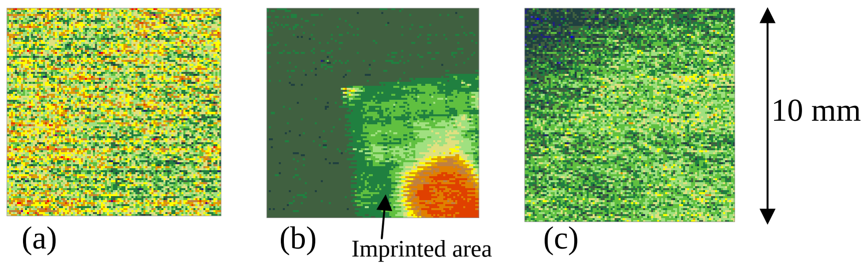

Fig. 1: Distributions of PL intensity from the epitaxial layer: (a) before NIL, (b) after NIL with resin, and (c) after removal of resin. No observable change in PL intensity is found between (a) and (c), indicating that the epitaxial layer of the laser diode have not been damaged by mechanical stress during the imprint.

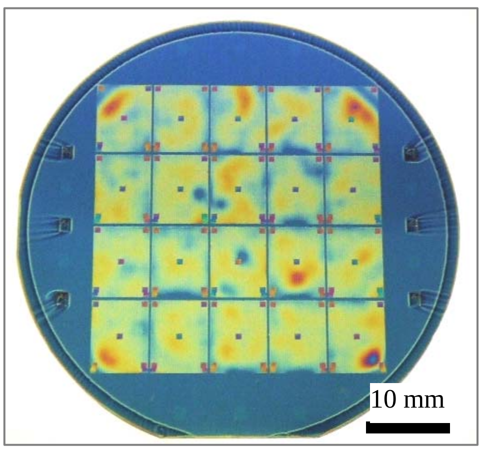

Fig. 2: Bird's-eye view of a 2-inch wafer after imprinting. Fringing patterns indicate the variations of residual layer thickness.

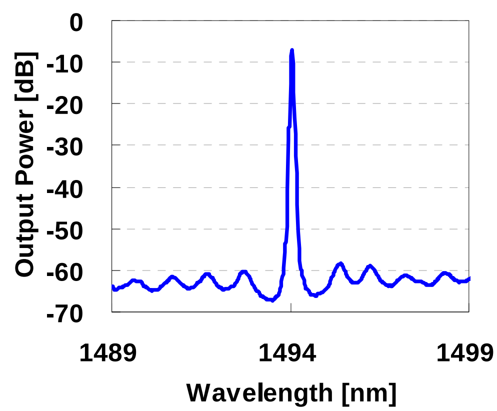

Fig. 3: An oscillation spectrum of a phase-shifted LD.

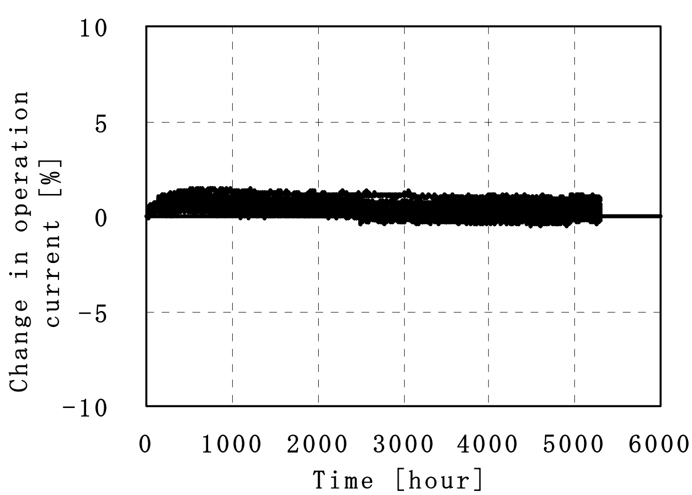

Fig. 4: Time-dependent change in operation current of DFB LDs with the output power of 10 mW at the ambient temperature of 85ºC.