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# Grating fabrication and characterization method for wafers up to 2 in

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**Abstract**

In the present paper, we describe a laser holographic system to fabricate first-order gratings with pitches from 190 to 250 nm, over the entire surface of 2 in epitaxial wafers. We present an operating procedure allowing good control of parameters that determine the mark/space ratio. The corrugation uniformity is measured by a mapping grating efficiency system. By using a buried guiding layer, we achieve good control of the coupling coefficient. An improvement of the fabrication yield for devices is shown by means of distributed feedback laser diodes results.

*Keywords*: Grating; Optoelectronic devices; Indium phosphide

## 1. Introduction

Today, distributed feedback laser diodes (DFB LD) emitting at wavelengths of 1.3 and 1.5 $\mu$m are key components for wide bandwidth optical communication systems. In general, these lasers need a first-order grating generated in a guiding layer close to the active layer. In the structure used, the guiding layer is embedded in InP layers. The coupling coefficient is determined by the thickness of the guiding layer and the spacer layer [1].

First, we briefly describe the holographic interferometer used to fabricate the grating. Then, we present the fabrication and characterization method. In this paper, we consider the improvement obtained by optimization of the exposure, development and plasma descumming. The diffraction efficiency, which relates directly to the height and shape of the grating, is measured on a set-up permitting a mapping on 2 in wafers.

## 2. Arrangement and method

The set-up used to fabricate the grating is a simple holographic interferometer [2]. The arrangement is shown in Fig. 1. Mechanical parts and optical components are assembled to form a stable system. The interferometer offers a pitch precision of less than 1 Å, with pitches from 190 to 250 nm. The light source is an argon laser emitting at a wavelength 351.1 nm on a single line in the TEMoo mode. A mobile acrylic cover ensures air stability during exposure. The divergent beams provide a good exposure homogeneity over more than 2 in, and produce a variation in grating pitch lower than 0.8 Å on a 2 in wafer. A computer controls the parameters, such as the equal intensities between the two beams, their stabilities, total energy and time for exposure. A small change in the interference angle is automatically carried out in a few seconds [3].

The wafers are carefully cleaned in an automatic wafer system, which deoxidizes the surface by dispensing sulfuric acid, with the aim of enhancing the photoresist adherence. The wafers are spin coated with a positive photoresist (Shipley 1805) which is diluted 1:3 with thinner. The layer thickness is chosen to be close to the antireflective conditions. The thickness is measured by ellipsometry; the variation of the photoresist thickness is lower than 2% for 2 in wafers. Exposed wafers are developed for 1 min on an automatic developer tool, with MF 351 diluted 1:6 with

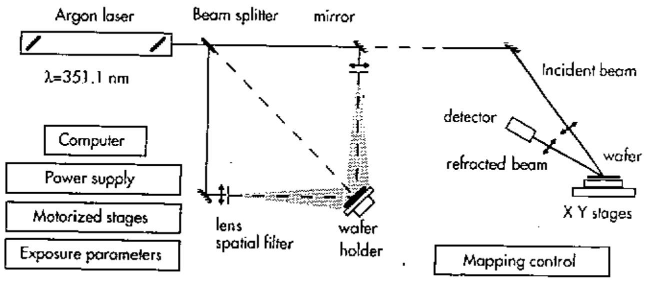


Fig. 1. Holographic arrangement for exposure, measuring and mapping.

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pure water. Because it is difficult to expose correctly down to the surface and to obtain a high amplitude of corrugations, we descum the photoresist at the bottom of the grooves, using an oxygen plasma [4]. Then, the wafers are etched in a solution of saturated bromine water, $H_3PO_4$ and water [5,6].

## 3. Characterization and optimization

We control the grating efficiency with a measuring unit at a wavelength of 351.1 nm. Measurement of the absolute diffraction efficiency on the photoresist without any profile modification is possible, provided the light power for measurement is lower than 10 mW $cm^{-2}$. Two- or three-dimensional mapping of the diffraction efficiency on the photoresist and etched wafers is performed in less than 8 min, using a focused beam (200 $\mu$m $\times$ 400 $\mu$m) (this equipment was developed by Scantek).

We have optimized the exposure dose and developing time. Fig. 2 shows the relationship between the efficiency on the photoresist and the dose—a variation from 8 to 12 mJ does not cause a large fluctuation of the efficiency. Fig. 3 represents a typical sinusoidal shape obtained on the photoresist. Fig. 4 shows the repeatability of the exposure from wafer to wafer. The relative variation of the diffraction efficiency on the photoresist is below 5%.

The $O_2$ plasma conditions have been determined to obtain a slow etching rate on the photoresist of 80 Å $min^{-1}$, in order to achieve good control of the shape of the photoresist mask. Fig. 5 shows a schematic diagram of the evolution of the profile; the photoresist thickness after the $O_2$ plasma is correlated with a mark/space ratio, which is the ratio between the photoresist mask and the space width. We can vary the mark/space ratio of the photoresist mask and, consequently, the width opening of grooves after wet etching. We use a mark/space ratio of 0.8, because the (100) planes of the surface are rapidly etched and the sidewalls formed by the (111) facets stop the etching.

A typical three-dimensional mapping of an etched wafer is shown in Fig. 6. An etched depth from 900 to

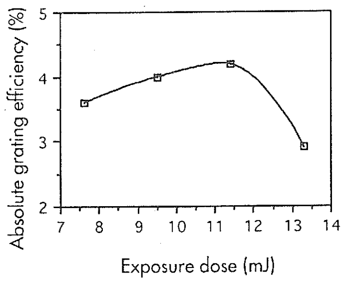

Fig. 2. Absolute diffraction efficiency vs. exposure dose.

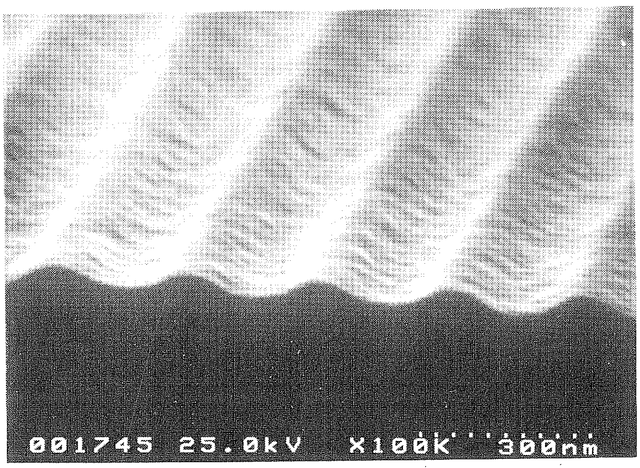

Fig. 3. SEM image showing the developed photoresist grating.

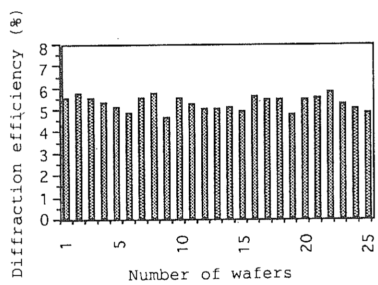

Fig. 4. Histogram of diffraction efficiency (%) in photoresist from wafer to wafer.

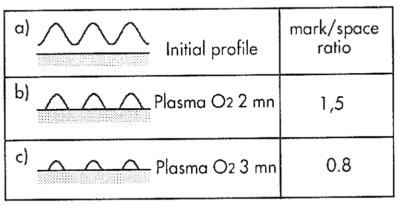

Fig. 5. Sketch of grating profiles: (a) initial profile with residual photoresist in the grooves; (b) descumming of the residual photoresist; (c) control of mark/space ratio.

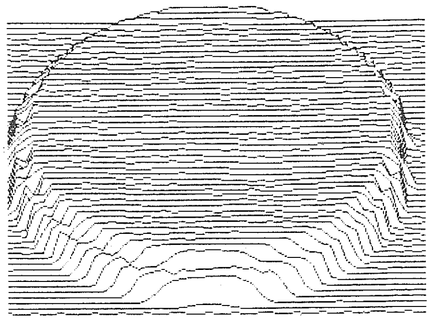
Fig. 6. Typical three-dimensional mapping of diffraction intensity in etched grating.

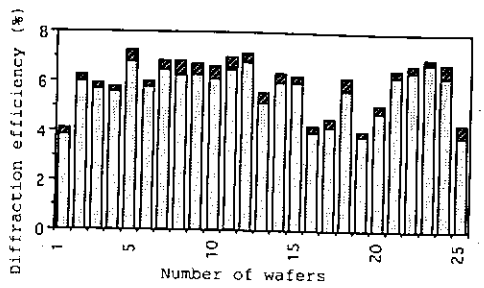


Fig. 7. Histogram of grating diffraction efficiency and variation (%) for a wavelength of 1.55 $\mu$m on a 2 in wafer (shading represents variations on each wafer).

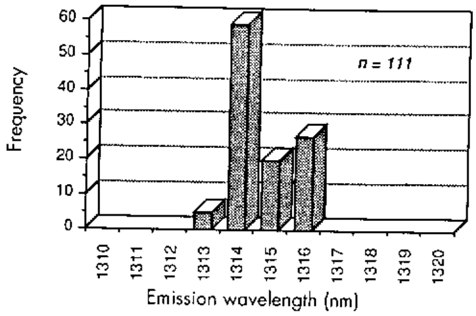


Fig. 8. Histogram of emission wavelength on a whole 2 in wafer. $n = 111$.

1200 Å ensures complete etching of the buried guiding layer; with this structure [7], a depth difference of 300 Å leads to a variation of the coupling coefficient of less than 30% [1]. The regrowth on the grating occurs by gas source molecular beam epitaxy [8].

All these improvements of the grating technology have increased the yield. A large number of wafers have been realized with this method; for example, Fig. 7 shows the absolute diffraction efficiency and homogeneity for etched gratings for a wavelength of 1.55 $\mu$m on a 2 in wafer.

## 4. Device results

Wafers for wavelengths of 1.3 and 1.55 $\mu$m have been made using this operating method. We present buried ridge structure DFB LD results for a wavelength of 1.33 $\mu$m [7]. Devices from five areas on the 2 in wafer are tested and mounted; for each area, we test around 30 chips. The wavelength for all the DFB chips is $\lambda = 1314.8 \pm 0.9$ nm (Fig. 8). This very good result indicates good control of the grating and active mesa. Fig. 9 shows a histogram of the threshold current; for $I_{th} < 15$ mA, the yield is 98%. We present in Fig. 10 a histogram of the side mode suppression ratio (SMR) at 6 mW, i.e. one of the principal characteristics for DFB LDs. For SMR > 35 dB, the yield is 45%, before any facet coating. The yield reduction is mainly attributed to the number of bimodal lasers, since no phase shift is used.

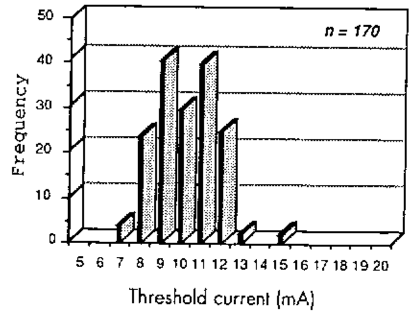


Fig. 9. Histogram of threshold current on a whole 2 in wafer. $n = 170$.

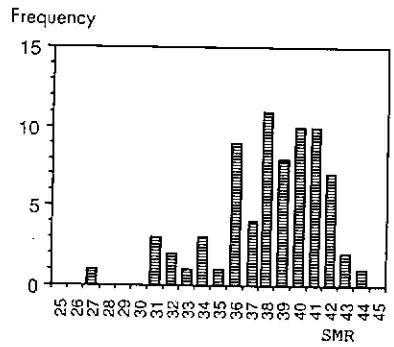


Fig. 10. Histogram of the side mode suppression ratio (SMR) at 6 mW (dB).

## 5. Conclusions

We have described a fabrication method for generating gratings on 2 in epitaxial wafers. The combination of $O_2$ plasma and characterization allows good control of the grating shape. The results obtained on devices indicate that we have made improvements with regards to diffraction homogeneity, repeatability and results for the devices.

## References

[1] A Takemoto, Y. Ohkura, Y. Kawama, Y. Nakajima, T. Kimura, N. Yoshida, S. Kakimoto and W. Susaki, *J. Lightwave Technol.*, *7*(12)(1989) 2072.
[2] W.W. Ng, C. Hon and A. Yariv, *IEEE Trans. Electron. Dev.*, *ED-25* (10)(1978) 1193.
[3] A. Bodéré, A. Accard, C. Artigue, M. Boulou and L. Legouzigou, *J. Nat. Microelec. Opto. III V*, (1990).
[4] L.F. Jhonson, G.W. Kammlott and A. Ingresoll, *Appl. Opt.*, *17*(8)(1978) 1165.
[5] T. Matsuoko and H. Nagai, *J. Electrochem. Soc.*, *133* (12) (1986) 2485.
[6] T. Nishida and T. Tamamura, *J. Electrochem. Soc.*, *140* (8) (1993) 2414.
[7] B. Fernier, A. Bodéré, G. Gelly, P. Pagnod and G. Vemdrome, submitted to *ECOC 94.*
[8] A. Accard, F. Brillouet, E. Duda, B. Fernier, G. Gelly, L. Goldstein, D. Leclerc and D. Lesterlin, *J. Phys. III, Fr. 2* (1992) 1727–1738.