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FABRICATION OF PHASE REFLECTION SAWTOOTH GRATINGS OPTIMIZED BY SCALAR AND VECTOR WAY BY USING DIAMOND CUTTING

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ABSTRACT

This paper presents optimization of phase reflection sawtooth gratings with a period of 2.0 μm and a depth of 0.2 μm based on the Fourier transformation (FT) and the rigorous coupled wave analysis (RCWA). And its fabrication on oxygen free Cu and electroless Ni-coated surfaces by using diamond cutting in a shaping process whose toolpath is interfered to provide smaller period. The diffraction efficiencies were estimated 100% for FT, 83.0% and 79.0% for TE and TM polarization of the incident light at a depth of 0.2 μm It was found that electroless Ni-coated surface had better performance in terms of machining and optical functionality. From optical testing, the diffraction efficiencies were measured 84.0% and 84.4% for TE and TM polarization, respectively.

INTRODUCTION

Recently, a great deal of research on surface relief gratings (SRGs) has been performed. SRGs play an important role in diffractive optical elements (DOEs). Also, DOEs bring the possibility for miniaturization in size and weight of the optical components (1). Keeping pace with these interests, a lot of analysis methods of diffractive gratings have been introduced (1,2). The most fundamental approach to the diffraction gratings starts with optical and geometric modeling. Many researches in this field have been performed, but mathematical manipulation would be so hard, so that, it is needed to turn to certain approximations to the general scalar diffraction theory. For the scalar diffraction analysis, it is valid only if the properties of gratings are large compared to the wavelength (3), and the Fourier transformation and the Fraunhofer diffraction theory are employed for the simplification and enable the grating model simple.

From the fabrication point of view, it is a key of how small period, how fine surface and how continuous profile of sawtooth gratings could be fabricated. In this paper, the toolpath is geometrically interfered to provide sawtooth gratings with smaller period on oxygen free Cu and electroless Ni-coated surfaces on STAVAX (Assab Co. Ltd.), and the fabrication results of two different materials are compared in terms of the existence of burr, waviness and cutting force. Also, diffraction efficiencies of the fabricated sawtooth gratings are evaluated through optical testing.

ANALYSIS

Among these analysis methods on gratings referred above, in this paper, the Fraunhofer approximation and the Fourier transformation for the scalar analysis and RCWA method for the vector analysis were employed for sawtooth gratings with a period of 2.0μm.

The mathematical representation of The Fourier transformation is shown in *Eq.* (1), where, $g(x)$ represents the geometric function of a periodic aperture and $E(x)$ is plane waves. k_x is referred as spatial frequency according to x direction. For the simplification, $E(x)$ is assumed to be constant if it is defined as plain waves based on the Fraunhofer approximation.

$$G(k_x) = \int_{-\infty}^{\infty} g(x)E(x)\exp(-ik_x x)dx, \qquad (1)$$

RCWA is a direct method to solve the governing set of the partial differential equations based on a state space representation without any assumptions (4). The general infinite sawtooth gratings were illustrated in figure 1.

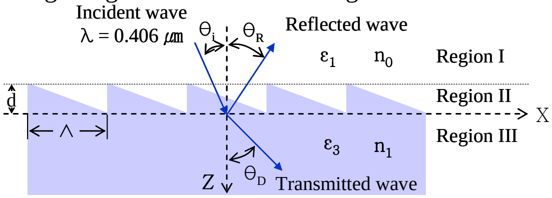


Figure 1 Geometry of general infinite sawtooth gratings

The analysis conditions of sawtooth gratings presented in this paper were indicated in Table 1. Figure 2 shows that at d=0.2 μm the best efficiency at the first-order efficiency was

$\eta_{r,1,SC}$=100.0% for the scalar approximation, $\eta_{r,1,TE}$=83.0%, $\eta_{r,1,TM}$=79.0% for TE and TM polarization, respectively.

Table 1. Optical and geometrical properties for analysis.

λ[㎛]	∧[㎛]	θ_i	n_0	Ni
0.406	2.0	0°	1.0	0.51-j4.95

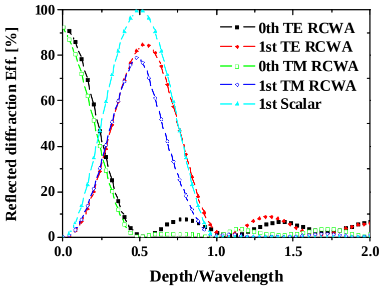


Figure 2 Efficiency curve; at d=0.2 ㎛, $\eta_{r,1,SC}$=100.0% for scalar analysis and $\eta_{r,1,TE}$=83.0%, $\eta_{r,1,TM}$=79.0% for RCWA.

RESULTS

Under the machining conditions indicated in Table 2, Main cutting forces applied on Cu and electroless Ni-coated surface along the cutting direction were measured and compared. From figure 3, it can be found that average cutting force on electroless Ni-coated surface, 0.018 N, was two times bigger than that on Cu, 0.008 N, and it depicts more stable than that of Cu surface. Sawtooth gratings with a period of 2.0 ㎛ and a depth of 0.2 ㎛ on Cu and electroless Ni-coated surfaces on STAVAX were fabricated, respectively. SEM and AFM measurement results of the fabricated surface were shown in figure 4. It was confirmed that electroless Ni-coated surface shows better machinability in terms of existence of bur and waviness.

Table 2. Machining conditions.

No.	Material	pitch ㎛	feed mm/min	Depth of cut ㎛	Area ㎟
1	Cu	2.0	5.0	2.0	500
2	electroless Ni	2.0	5.0	2.0	500

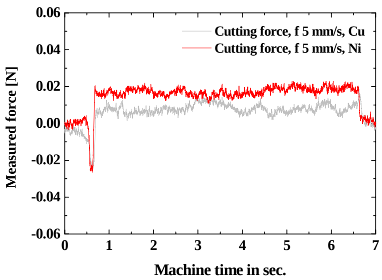
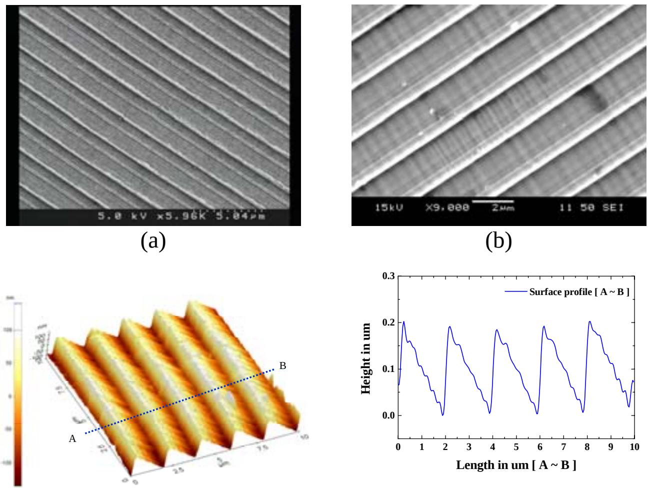


Figure 3 Cutting force measured from a dynamometer; Cu-average 0.008 N, electroless Ni-coated 0.018 N.



(a) (b) (c) (d)

Figure 4 Measure data by SEM and AFM; (a) Cu, (b) elecroless Ni-coated, (c) AFM, electroless Ni-coated surface, (d) surface profile between point A and point B.

From optical testing, the first order efficiencies were measured 84.0% and 84.4% for TE and TM polarization, respectively. Also, the diffracted angle was measured, 11.3 in degree. These results have good agreement with results theoretically calculated by RCWA. The only differences in the theoretical and experimental values were within a few percent in spite of variation in the peak wavelength of laser source (±7 nanometer).

CONCLUSION

Analysis and fabrication of sawtooth gratings with a period of 2.0 ㎛ and a depth of 0.2 ㎛ were performed. The optical and geometric diffraction properties of sawtooth gratings for analysis were investigated and optimized for the best efficiency at the first order diffraction efficiency by the scalar and vector analyses. Fabrication results showed that Ni-coated surface had the better machinability and functionality than oxygen-free Cu surface in terms of the existence of burr and waviness. From optical testing, the first order efficiencies were measured 84.0% and 84.4% for TE and TM polarization, respectively. Also, the diffracted angle was measured, 11.3 in degree. These results have good agreement with results theoretically calculated by RCWA.

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