Fabrication of blazed gratings used in ultraviolet region by holographic ion beam etching based on photoresist melting

LI Wen-hao[1,2], Bayanheshig[1], QI Xiang-dong[1], and TANG Yu-guo[1]

1. Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Changchun 130033, China;

2. Graduate School of Chinese Academy of Sciences, Beijing 100039, China

(Received 18 October 2007)

A novel technology to manufacture holographic ion beam etched diffraction gratings based on surface thermokinematics is presented. The surface roughness of photoresist gratings is solved by this technology. According to this technology, a holographic ion beam etched blazed grating of 1200 l/mm for use in the ultraviolet region is manufactured. The experimental results show that the grating has good surface quality, low stray light and high diffraction efficiency. In addition, the performance of thes gratings satisfies the operating requirements of ultraviolet spectrograph.

CLC numbers: TN253 **Document code:** A **Article ID:** 1673-1905(2008)03-0177-3

DOI 10.1007/s11801-008-7140-5

In the process of exposure and development the groove surface of photoresist grating is coarse due to the asymmetric light distribution, the defect of the optical elements, and the stray light. If the photoresist grating used as a mask plate has a surface as mentioned above and is etched by ion beams, the defects will be duplicated partially or entirely on the surface relief grating. As a result, the property of grating can be severely influenced. Although the groove surface of photoresist grating can be smoothed by reactive ion etching method, the cost will be higher and the fabrication period is longer.

Photoresist melting method, due to its low-cost, short process period and to be controlled easily, is reported as an effective method to reduce the surface roughness of photoresist relief in recent years [1-6]. we have applied this technique to the fabrication of holographic gratings in order to reduce surface roughness, and have obtained many satisfying results.

The purpose this paper is to expatiate on the principle of the photoresist melting method and to demonstrate the feasibility of this method by specific technological process and the experimental results of an ultraviolet blazed grating of 1200 lines/mm.

Fig.1 shows the experimental setup of exposure. The light beam reflected by a plane mirror M2 intersects another beam reflected by the plane mirror M2 at an angle 2θ, and the interference field of them is the exposure region. If a substrate coated with photoresist is inserted in this region, fringes will be recorded with a spacing d given by

$$d = \frac{\lambda}{2n\sin\theta\cos\delta} \tag{1}$$

where λ is the wavelength of laser, n is the refractive index of recording space, and δ is the angle between normal directions of the substrate and the bisector of the beams.

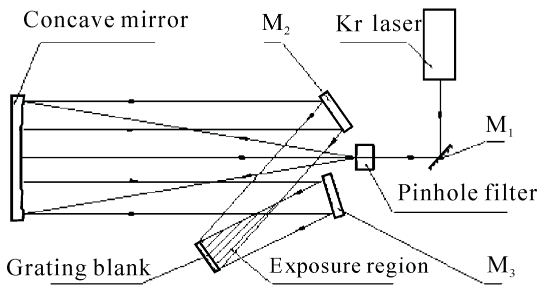

Fig.1 The holographic light path of the exposure

Based on surface thermokinematics, a liquid drop will be in equilibrium state when a definite contact angle is applied on the solid surface. Young's model describes a liquid drop on a solid smooth, flat and uniform surface of solid as

$$T_{AL}\cos\theta = T_{SA} - T_{LS} \tag{2}$$

* E-mail:leewenho@163.com

where θ is the equilibrium contact angle (Fig.2), T_{AL} is the surface tension energy of the liquid, T_{SA} is the surface tension energy of the solid, and T_{LS} is the solid-liquid interface energy. This principle is an absolutely correct description of the interface between the K9 glass substrate and the photoresist in melting state. The contact angle θ between the photoresist and the K9 glass substrate is a constant, which is related to the chemical constitution of the photoresist, the sarvounding gas and the substrate property.

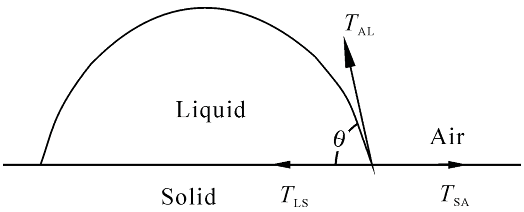

Fig.2 Contact angle equilibrium

In the experiment, a Kr^+ ion laser with an output wavelength of 413.1nm is used to record the interference fringes with a period of 0.833 μm in air. At the condition of δ=0 by the reasonable design, θ=14.35° is obtained.The K9 glass substrate with coated photresist is placed in the exposure region.

Fig.3 shows the AFM of photoresist grating with the appropriate exposure and developing times. As can be seen that the groove of the photoresist grating has a uniform configuration and is isolated to each other after the sufficient development, but with many bulges appearing on the surface.

In the melting process, the photoresist grating is heated in the baking oven, to make the surface roughness smaller by surface tension[11]. Because the photoresist belongs to the amorphous polymer containing many kinds of chemical constitution, its melting point is within a temperature range, instead of at a fixed temperature. The temperature range used is 160 -180 ℃ for 30 min in the experiment. This appropriate choice of the melting parameters can minimize the surface roughness. After the photoresist is melted, the surface structure of the grating is obtained as shown in Fig.4.

From Fig.3 and Fig.4 we can see that the surface structure becomes smooth and regular due to surface tension. The surface roughness reduces because of the obviously decreasing bulge. The profile of the transverse section is changed from the sinusoidal form into the circular arc form.The period of photoresist grating holds the line, while the maximal height of it declines.

Because the physical features and the optical performances of photoresist grating are far better than that of holographic grating in K9 glass substrate. The surface structure is transferred from the photoresist to K9 glass substrate. This procedure is achieved by using Ar^+ ion-etching technique. The grating with a random blazed angle is fabricated by adjusting the depth-width ratio of groove and the incidence angle of ion beam.

Fig.5 shows the AFM of surface relief grating obtained by etching the melted photoresist grating. The surface of the grating after being melted becomes smooth and the groove shape becomes regular.

A holographic grating is fabricated after the surface relief grating is coated with aluminum by vacuum evaporation.

Photoresist melting method has the characteristis of low-cost, short-period and easy to be realized, by which we have

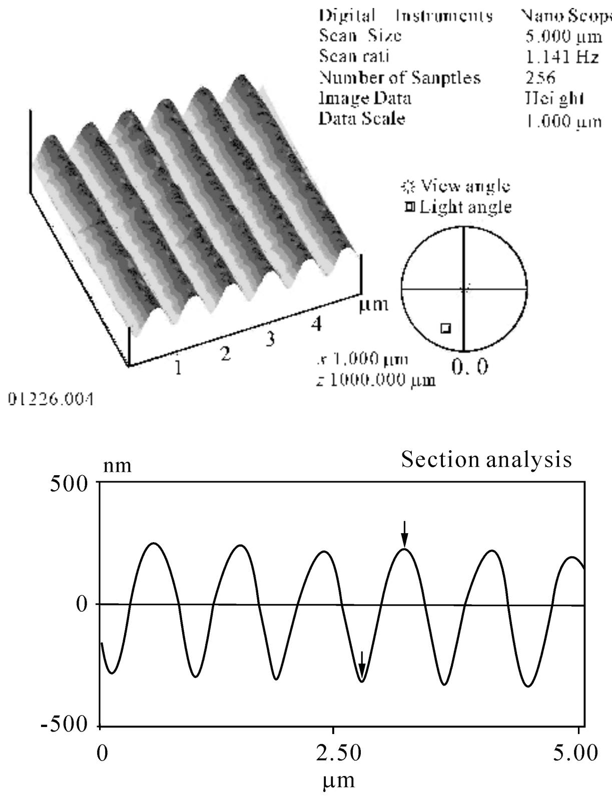

Fig.3 Three-dimensional configuration and profile chart of the photoresist grating after the exposure and developing process