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

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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 spectograph.


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

\[ d = \frac{\lambda}{2n \sin \theta \cos \delta} \]  

(1)

where \( \lambda \) is the wavelength of laser, \( n \) is the refractive index of recording space, and \( \delta \) is the angle between normal directions of the substrate and the bisector of the beams.

![Fig.1 The holographic light path of the exposure](image)

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

\[ T_{AL} \cos \theta = T_{SA} - T_{LS} \]  

(2)
where \( \theta \) is the equilibrium contact angle (Fig.2), \( T_{AL} \) is the surface tension energy of the liquid, \( T_{ls} \) 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 photore sist in melting state. The contact angle \( \theta \) between the photore sist and the K9 glass substrate is a constant, which is related to the chemical constitution of the photore sist, the surrounding gas and the substrate property.

In the experiment, a Kr* ion laser with an output wavelength of 413.1 nm is used to record the interference fringes with a period of 0.833 \( \mu \)m in air. At the condition of \( \delta=0 \) by the reasonable design, \( \theta=14.35^\circ \) is obtained. The K9 glass substrate with coated photore sist is placed in the exposure region.

Fig.3 shows the AFM of photore sist grating with the appropriate exposure and developing times. As can be seen that the groove of the photore sist 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 photore sist grating is heated in the baking oven, to make the surface roughness smaller by surface tension\(^{11} \). Because the photore sist 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 \( ^\circ \)C for 30 min in the experiment. This appropriate choice of the melting parameters can minimize the surface roughness. After the photore sist 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 photore sist grating holds the line, while the maximal height of it declines.

Because the physical features and the optical performances of photore sist grating are far better than that of holographic grating in K9 glass substrate. The surface structure is transferred from the photore sist 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 photore sist 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.

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