

An Introduction to Phase Masks

When specifying standard or custom phase masks there are a few important steps and calculations required to ensure the final device operates as intended. This paper will help to examine the overall configurations and formulas needed when specifying your next mission critical phase mask.

Introduction to Phase Masks

Phase masks are surface relief gratings, typically etched in fused silica as shown in (Figure 1). In most applications, a phase mask essentially serves as a precision diffraction grating that divides an incident monochromatic beam, typically in the UV spectral range, into two outgoing beams. These two exit beams create an interference pattern in the region in which they overlap, illustrated in (Figure 2).

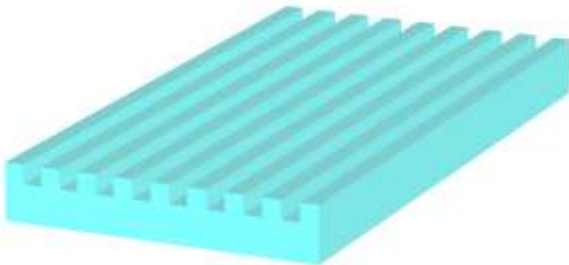


Figure 1. Phase masks are surface relief gratings etched in fused silica.

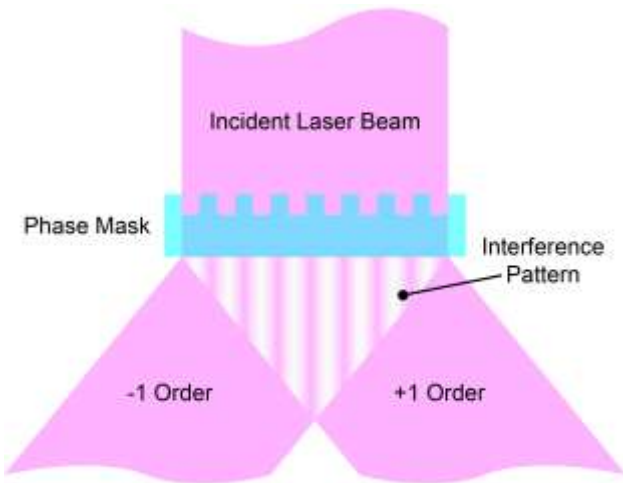


Figure 2. A phase mask produces two diffracted beams, and an interference pattern is created where they overlap.

Phase masks have a wide variety of applications, but most frequently, PMT phase masks are used to record other gratings. Typical examples of these are planar waveguide gratings used in integrated optics devices, and fiber Bragg gratings (FBGs). An FBG is a periodic modulation in the refractive index of the core of an optical fiber, and is usually employed to create high reflection properties at one or more wavelengths.

Phase Mask Configurations

Most phase masks are fabricated in UV-transparent fused silica of high purity, but other materials are available as well. The [data sheets](#) accessible provide an overview of the ranges of various phase mask parameters for our standard products.

The "period" (or "pitch") of phase mask gratings range from a few hundred nanometers to almost 2000 nanometers (2 microns). The grating areas come in a wide variety of dimensions, ranging from a few millimeters square to 10 mm by 120 mm. The silica substrates on which the phase mask gratings are etched are typically 1/8" thick. The grating profile is essentially binary (a rectangular wave) for the longer periods, and tends to be somewhat quasi-sinusoidal for the shorter periods.

Phase masks are typically employed in one of two configurations, +1/-1 or 0/-1, where the numbers refer to the diffracted orders which contain the bulk of the diffracted light.

In the +1/-1 configuration, the UV radiation is directed with normal incidence at the phase mask, and the period of the fringe pattern generated by the interference of the outgoing beams is exactly one half of the period of the phase mask grating as shown in (Figure 3). In the 0/-1 configuration, the UV radiation is directed at the phase mask with a specially chosen angle of incidence, and the period of the fringe pattern is exactly equal to the period of the phase mask grating.

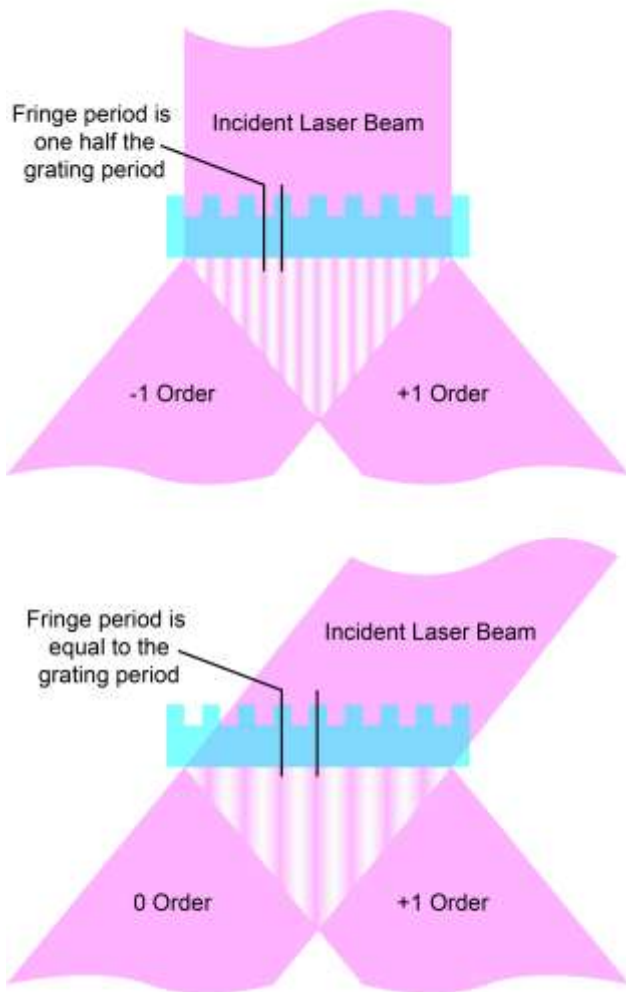


Figure 3. Schematic representation of phase masks configured in the -1/+1 (top) and 0/-1 (bottom) configurations.

The upper part of Figure 4 is a schematic depiction of the recording of an FBG in the +1/-1 configuration. UV radiation is normally incident on the phase mask. A pattern of fringes, which are stationary alternating zones of high and low intensity, is generated by the interference of the two outgoing beams. A length of optical fiber (usually made of silica) is placed in this interference pattern. The fiber's core has been rendered photosensitive, usually through doping with oxides of germanium, tin, boron, phosphorus and other elements. Due to this photosensitivity, the refractive index of the core is altered through exposure to UV radiation. Thus, exposure to the interference pattern causes a periodic modulation of the index of refraction in the core material. The result is a fiber Bragg grating (FBG), shown in the bottom part of the figure.

In operation, the FBG acts as a narrow band reject filter as illustrated in (Figure 5). Specifically, one wavelength is highly reflected by the FBG, while the

other wavelengths pass through unattenuated. FBGs are located at the heart of many fiber sensing devices and telecom components. They are fundamental building blocks in many fiber systems.

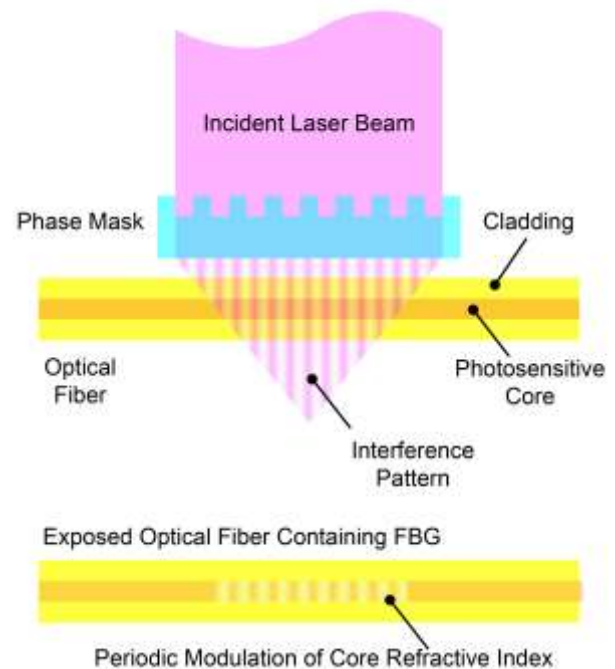


Figure 4. Phase masks, which are themselves gratings, are used to record other gratings, such as fiber Bragg gratings (FBGs).

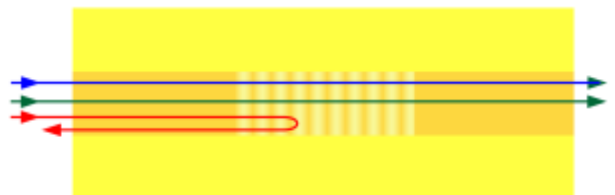


Figure 5. A Fiber Bragg Grating is a wavelength selective filter located in the core of an optical fiber.

Phase Mask Formulas

When a phase mask is operated in the +1/-1 configuration, the UV light is normally incident on the grating as shown in (Figure 6). The angles of diffraction $\Theta_0, \Theta_{-1}, \Theta_{+1}, \Theta_{-2}, \Theta_{+2}$ etc. are given in terms of the UV wavelength λ_{UV} and the phase mask period Λ_{PM} , by the formula

$$\sin\Theta_m = m \lambda_{UV} / \Lambda_{PM}$$

The period of the fringe pattern created by the interference of the +1 and -1 beams is exactly one half of the period of the phase mask, regardless of the wavelength of the incident radiation.

$$\Lambda_{\text{fringe}} = \Lambda_{\text{PM}} / 2$$

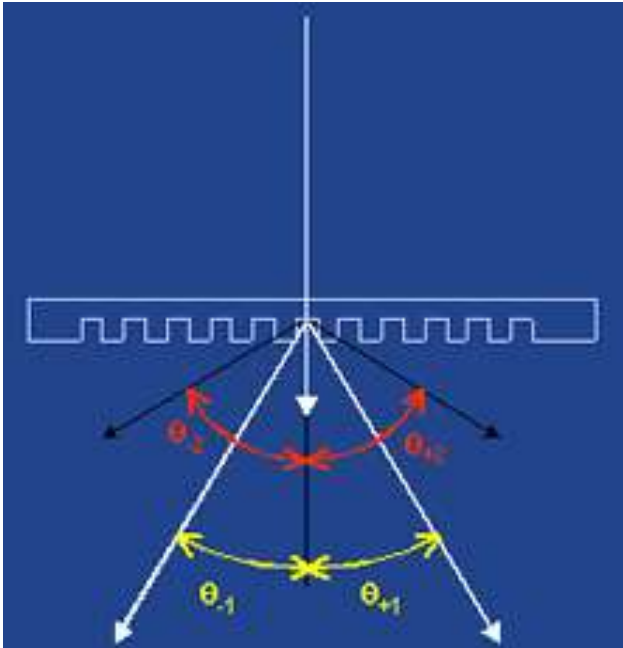


Figure 6. +1/-1 Phase Mask Configuration

PMT's phase masks are optimized so that the intensity of the +1 and -1 orders is maximized, while the intensity carried in the zeroth order is minimized. Also, the intensity in any higher orders ($m = \pm 2, \pm 3$, etc.), if such orders are present, is also minimized.

A phase mask can also be operated effectively in the 0/-1 configuration, as depicted in Figure 7. This configuration is defined by the condition $|\Theta_0| = |\Theta_{-1}|$, which ensures that the fringes are perpendicular to the phase mask surface.

In order to satisfy this condition, the required angle of incidence is:

$$|\sin \Theta_{\text{in}}| = |\sin \Theta_0| = \lambda_{\text{UV}} / (2 \Lambda_{\text{PM}})$$

Moreover, if the condition $(2/3) \Lambda_{\text{PM}} < \lambda_{\text{UV}} < 2 \Lambda_{\text{PM}}$ is satisfied, then there will be one and only one diffracted

order (the -1 order) and no other orders (such as +1, $\pm 2, \pm 3$, etc.). In other words, there are two and only two outgoing beams: the 0 order and the -1 order. This guarantees a clean fringe pattern.

The period of the fringe pattern created by the interference of the 0 order and -1 order beams is exactly equal to the period of the phase mask period.

$$\Lambda_{\text{fringe}} = \Lambda_{\text{PM}}$$

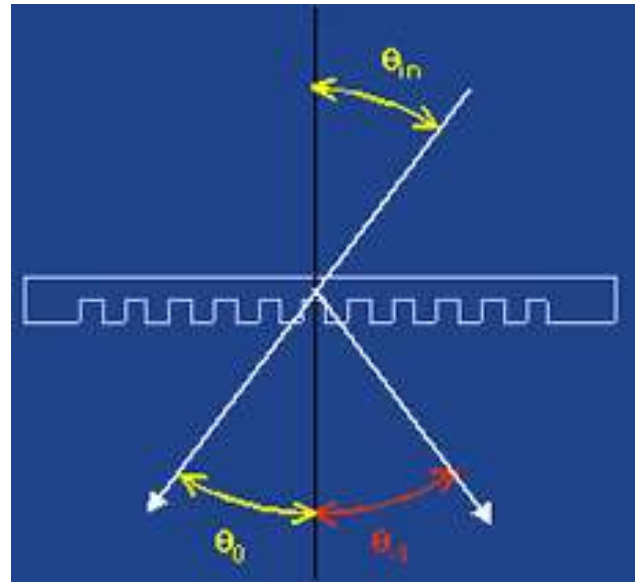


Figure 7. +0/-1 Phase Mask Configuration

This remains true regardless of the wavelength of the incident radiation, and regardless of whether the condition $|\sin \Theta_{\text{in}}| = \lambda_{\text{UV}} / (2 \Lambda_{\text{PM}})$ is perfectly achieved.

Conclusion

PMT holographically produced phase masks are high precision components, suitable for the most demanding applications, such as Fiber Bragg Grating writing. However, it is necessary to understand the basic operational principles of phase masks and how to properly specify them in order to obtain optimum performance from these devices.