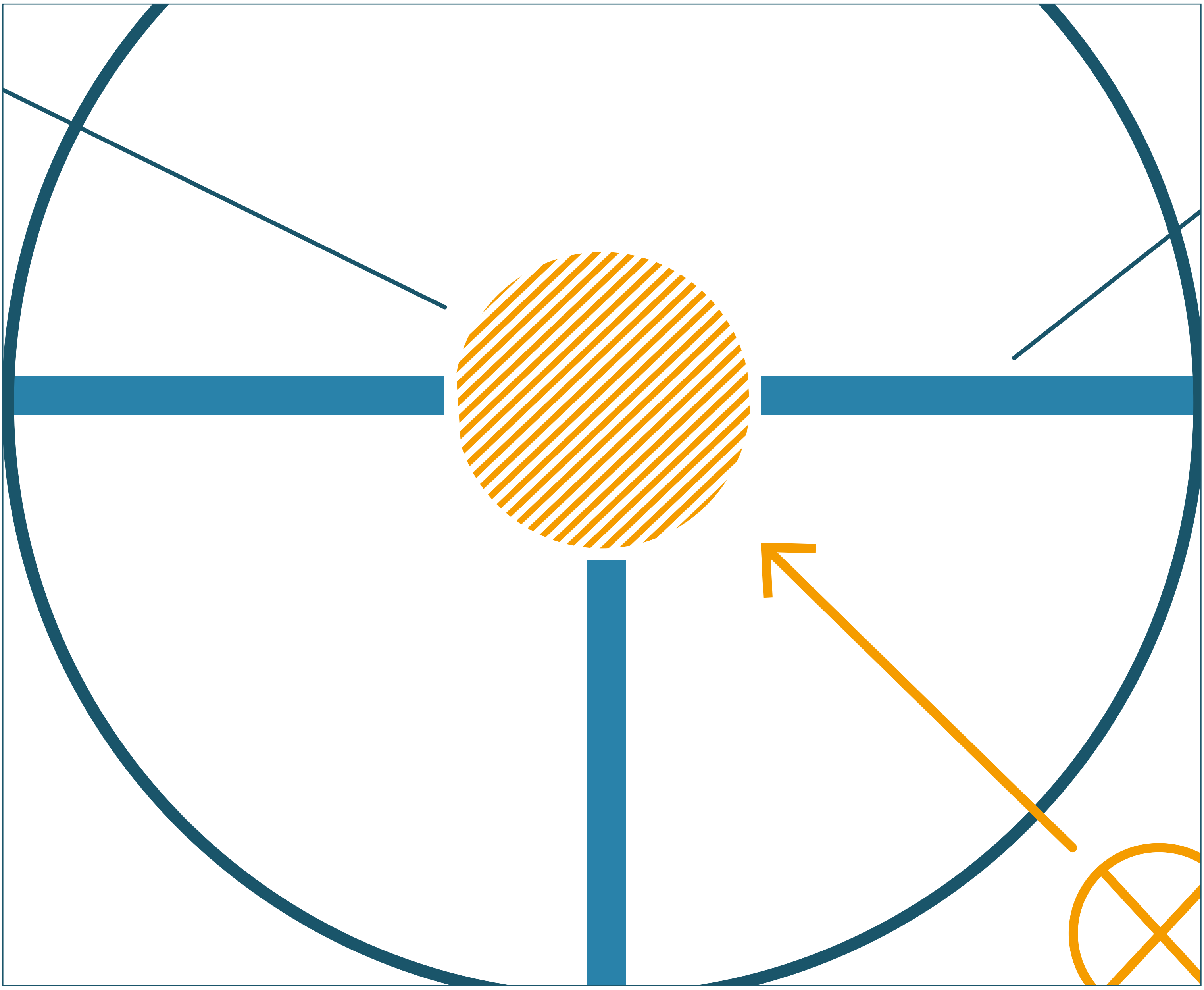
Illuminated Reticle Technologies for Rifle Scopes

A comparison of the diffraction grating technology with etch-and-fill



Introduction

An optical aiming device (rifle scope) that enables fast and accurate target acquisition under almost all light conditions offers essential value for the user. The requirement to the ideal performing scope is that the outline of the reticle pattern (i.e. crosshair, MIL-dot, circle-dot, etc.) must be visible when aiming under all light conditions (from low light at dusk as well as in bright daylight). It is also a requirement that the reticle pattern appears as dark as possible when not illuminated.

Illuminated reticles can be obtained by implementing different technologies: the well known etch-and-fill or the novel diffraction grating technology of IMT. This document compares the two technologies and describes the technical principles.

Diffraction grating technology

Using the diffraction phenomenon (instead of scattering) to generate an illuminated reticle is a novel concept that offers a superior level of brightness, allowing the usage of the aiming device under bright daylight conditions.

When collimated light passes through a multiple slit system (or grating as illustrated in figure 1) diffraction takes place. This results in many emergent beams or diffraction orders, whereas the first order is the order of interest in this case. As shown by the formula in figure 1 the diffraction angle is directly related to the wavelength of the incident light and to the grating period. The smaller the grating period is, the larger the diffraction angle.

In aiming and targeting devices (rifle scope, range finders, etc.) the light source is located on the side of the reticle and the diffracted light (first order) emerges on the optical axis (direction of the observer, see figure 2). To get a high diffraction efficiency the illumination angle **α** should not exceed 60°. Depending of the reticle thickness this condition can only be fulfilled by using a total internal reflection (see right hand side of figure 2). For an illumination angle $\alpha = 60°$, a refractive index $n_G = 1.52$, and a wavelength $\lambda = 630$ nm (red) one gets $p = 478$ nm (submicrometric grating period).

According to the diffraction theory, the first order of diffraction emerges with quite a high intensity level. Two first order beams are generated, but only one is useful. The angular distribution of the diffracted light is mainly determined by the distribution of the illumination (please refer to figure 3). The use of collimated or slightly focused light for the illumination therefore generates a very high intensity allowing the usage of the illuminated reticle under daylight conditions.

Figure 1 | Light diffraction on a grating

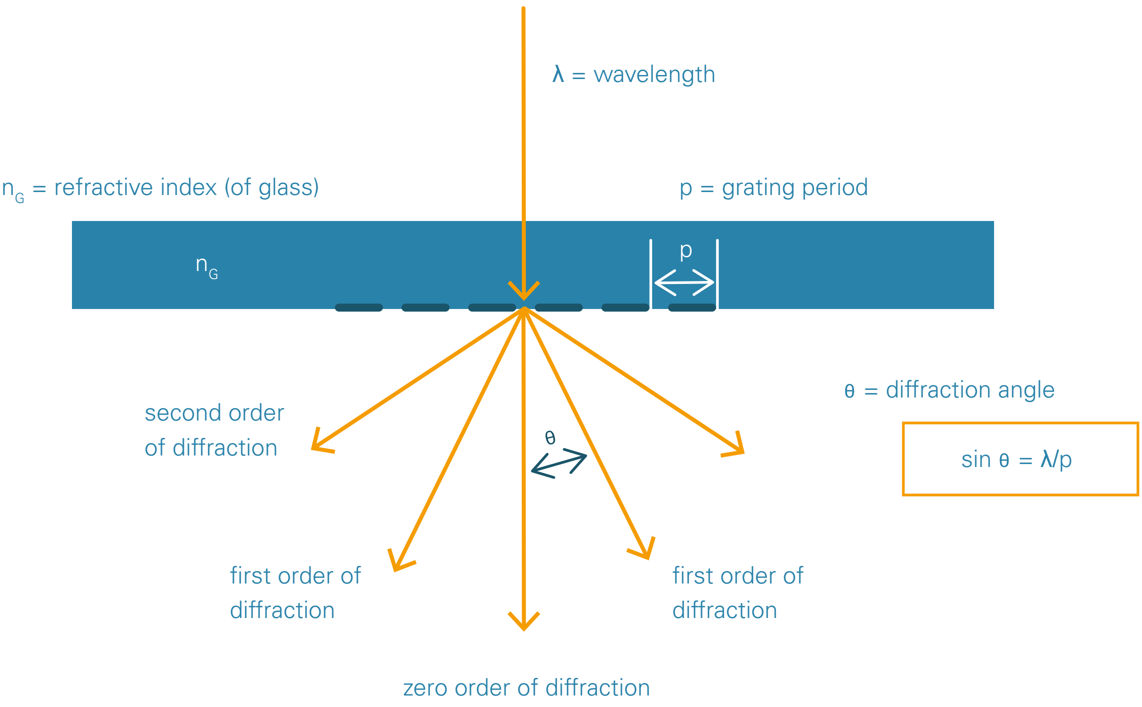
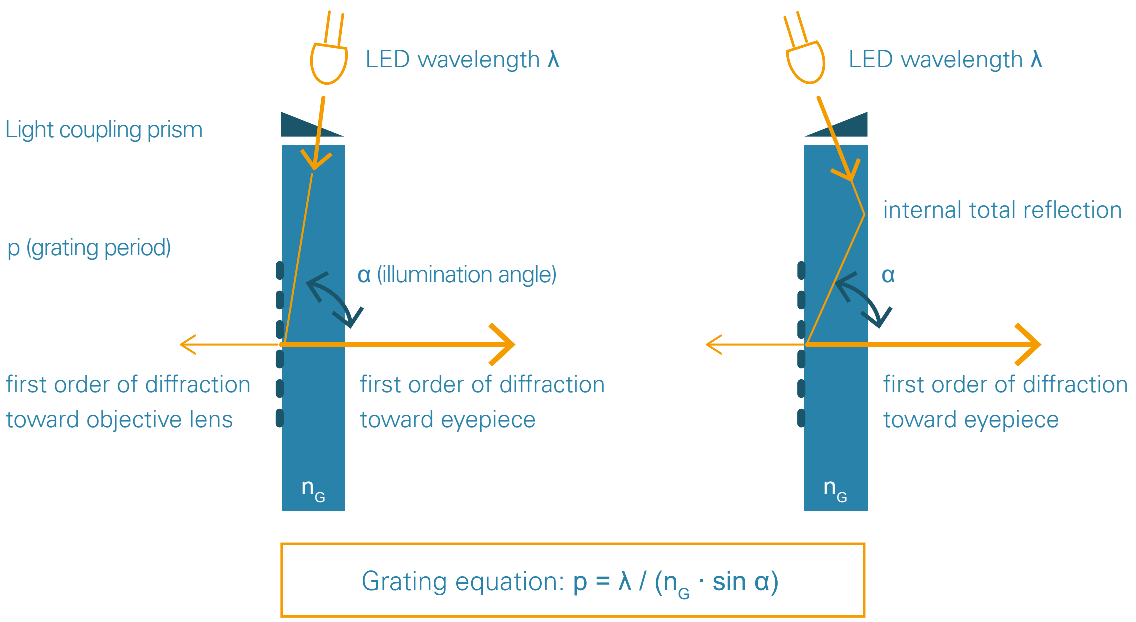


Figure 2 | Use of the first diffraction order



For an ideal use of diffraction gratings the following parameters need to be considered:

- Wavelength of the light source (illumination).
- Orientation of the light source perpendicular to the grating (see figure 4).
- Light coupling method and illumination angle.
- Optical properties of the reticle edge (surface roughness).
- Aperture of the distribution of the light source.

Two kinds of gratings can be used, namely amplitude or phase gratings allowing following possibilities:

1. By using an amplitude grating (transparent gaps and opaque chromium lines) the fiducial marking can be used as a classical chrome reticle when illumination is turned off.
2. To avoid the unwanted first order which travels toward target (see figure 2) IMT proposes a phase grating with chrome cover (phase grating in reflection).
3. By using a phase grating in transmission (means without chrome cover) the illumintated pattern will remain nearly invisible when light is switched off.
4. Two patterns can be independently illuminated by using crossed grating structures and two illumination LEDs.

Advantages (PROS) and disadvantages (CONTRAS) of the diffraction grating technology:

PROS:

- Strong radiation on the optical axis, generating sufficient light to allow usage under daylight conditions.
- Inalterable reticle (no white paint, no radioactive decay, etc.).
- Very sharp reticle pattern.
- Can be used for target acquisition also when not illuminated.
- No light towards target for enhanced security (by using a phase grating in reflection).
- Invisible pattern when light is switched off.
- Single or multiple illuminated patterns possible.
- Cover glass possible.
- Feature size down to 3 μm.

CONTRAS:

- The light coupling requires more attention in comparison with etch-and-fill reticles.

Figure 3 | Angular distribution of the light in the first diffraction order

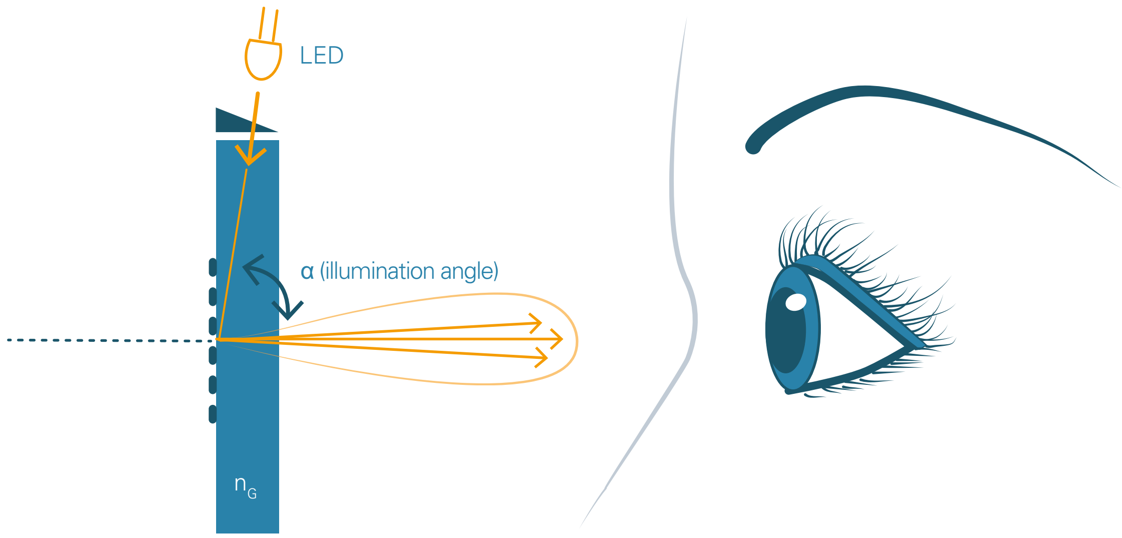
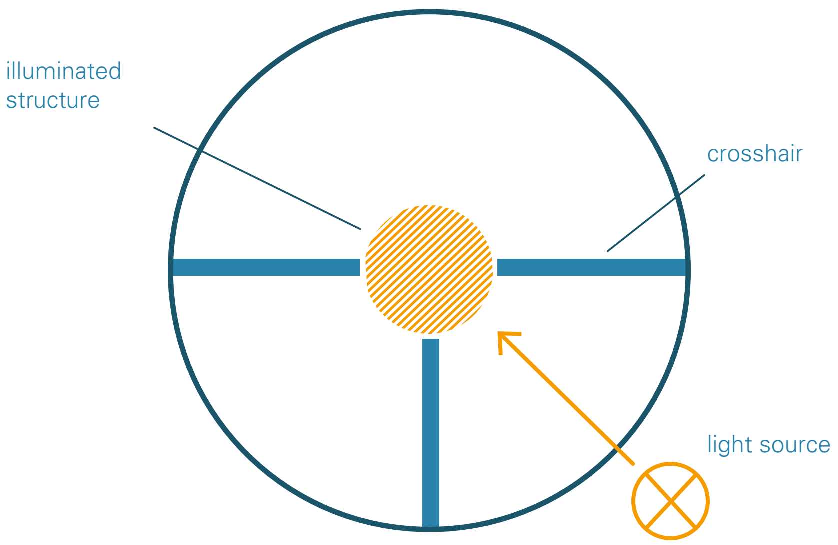


Figure 4 | Orientation of the light source



Etch-and-fill technology

With this technology the reticle pattern is etched into the glass substrate (a few micrometers deep) and then filled with pigments using a binder material. When laterally illuminated (mostly using a LED) it scatters the light in all directions (as illustrated in figure 5). A certain amount of light is directed toward the observer (shooter) through the eyepiece offering a good contrast between the reticle and the target.

The light radiation is more or less according to Lambert's cosine law (see figure 6). Lambert's cosine law states that the total radiant power observed is directly proportional to the cosine of the angle θ between the observer's line of sight and the surface normal.

Without illumination the reticle pattern shows a dark aspect due to the light absorption in the filling material.

The etch-and-fill technology requires two successive lithographic processes, first one for the illuminated structure, then one for the crosshair. A mask aligner is required to ensure a perfect alignment of the two structures within a few micrometers.

In order to get a good homogeneity as well as sharp edges of the reticle pattern, it is necessary to address the matter of the filling material (binder + pigments) with outmost care.

Advantages (PROS) and disadvantages (CONTRAS) of the etch-and-fill technology:

PROS:

- Easy implementation (illumination is not critical).

CONTRAS:

- Etch-and-fill structures do not generate enough light to be used under daylight conditions because of the broad angular distribution of the light (see figure 6). Only a small amount of the light is deviated toward the observer (shooter).
- Complex manufacturing process.
- Feature size below 6 µm is critical.

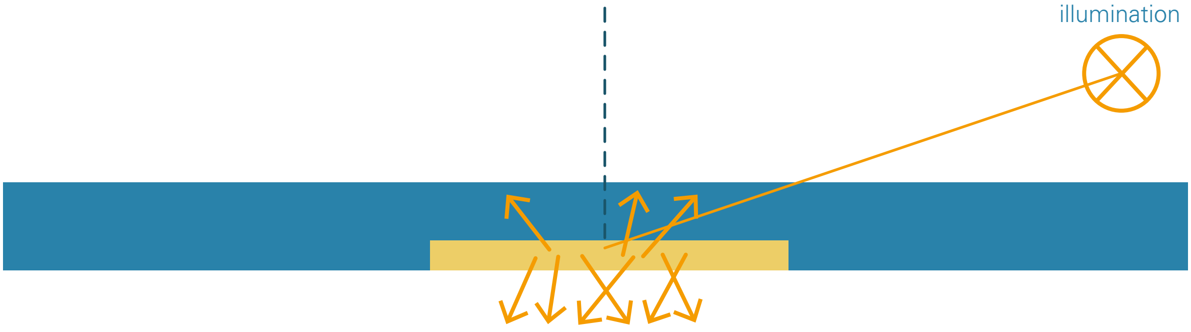
Conclusions

Illuminated reticles based on diffraction gratings offers a much higher brightness compared to those based on etch-and-filled principle (light scattering). They can therefore be utilized in both daylight and dusk light conditions. The diffraction technology also offers a wide variety of applications.

To be able to take the full advantages of the diffraction gratings, the light coupling requires more attention in comparison with etch-and-fill reticles. The shape of the illumination beam has to be well designed.

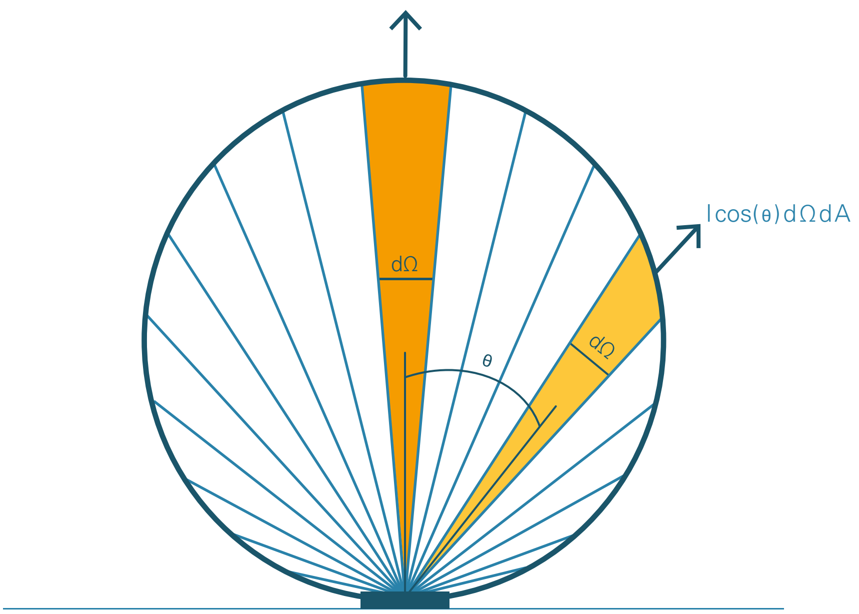
The use of the diffraction technology for reticle is patented. IMT owns this patent.

Figure 5 | Etch-and-fill structure



Fiducial marking structure etched and filled
with pigment particles assuring light scattering

Figure 6 | Lambert's law



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