Perfect blazing with echelle gratings in Littrow mount

Bernd H. Kleemann
Corporate Research and Technology, Carl Zeiss AG Oberkochen
mailto:b.kleemann@zeiss.de

Perfect blazing with echelle gratings in a high order Littrow mount really exists simultaneously in TE and TM polarizations. It is a phenomenon, searched more than 60 years long and assumed not to exist the past 20 years! As a matter of fact, in the ideal case of infinite conductivity, all light is diffracted into the Littrow order with 100% efficiency for both polarizations and there is no directed stray light.

1 Introduction

The property of gratings to concentrate the major part of the diffracted light into a specific order is called *blazing*. It is *perfect* when no light goes elsewhere, hence all incoming light is diffracted into only one diffraction order. For real metallic gratings, absorption losses and diffuse scatter may occur.

The search for perfect blazing with echelle gratings started at the end of the 1950ies and went on from the 1960ies to the 1990ies. During that time several findings have been made: it has been found perfect blazing for TM polarization, for TE polarization, and also simultaneously for TE and TM polarizations (for binary gratings only). It has been found perfect blazing for echelette gratings, for binary gratings, for sinusoidal, and for triangular gratings. Nevertheless, all these findings of perfect blazing were valid only in the first order or in another low order application.

Perfect blazing in a high order application has never been found before. And perfect blazing simultaneously for TE and TM polarizations for echelle gratings has never been found before, as well.

So, understandably, the property of perfect blazing simultaneously for TE and TM polarizations with echelle gratings was assumed not to exist. And there were given some explanations by a couple of well known grating specialists why it cannot exist [1].

Hence, we are presenting a property which has been searched more than 60 years long and assumed not to exist the past 20 years!

2 First proof

The first proof for perfect blazing simultaneously for both polarizations with an echelle grating in a high order Littrow mount was recently given in [1] with the help of electromagnetic diffraction theory. It was shown that 100% efficiency is reached in the ideal case of infinite conductivity. This case corresponds to the relevant spectral range of infrared wavelengths with the conductivity being large enough to be assumed to be infinite.

Additionally, perfect blazing was shown in [1] for an aluminum echelle grating of finite conductivity with complex refractive index $n = 0.113 + \mathrm{i}2.207$ having an apex angle of $90°$, in the ultraviolet spectral range at a wavelength $\lambda = 193.3$nm. The grating period is $d = 8794$nm, the Littrow angle is $\theta_\mathrm{L} = 78°$, working in the 89. Littrow diffraction order. Then perfect blazing appears for a blaze angle of $\alpha_\mathrm{b} = 84°$ with nearly no directed stray light at all. Due to absorption, maximal efficiency in the Littrow order is 92.2% in TE and 87.9% in TM polarization.

3 Observations

The most astonishing observation is the fact that blaze angle for perfect blazing $\alpha_\mathrm{b} = 84°$ is not equal to the Littrow angle $\theta_\mathrm{L} = 78°$ by that large difference of 6°. In Littrow configuration, the two angles are usually equal! This leads us directly to the next observation [2]: the 6° difference is half of the difference between θ_L and 90°: $6° = \frac{1}{2}(90° - 78°)$. Hence it turns out that for the blaze angle of maximal efficiency there holds:

$$\alpha_\mathrm{b} = \frac{1}{2}\theta_\mathrm{L} + 45°. \quad (1)$$

In words: the blaze angle is equal to the angle for which the specular reflection of the incident light on the blaze facet is parallel to the grating plane.

4 Conditions

Necessary conditions for perfect blazing in a high order Littrow mount are, for instance, a $90°$ apex angle and a specific Littrow order L given by the following formula

$$L = [2\sin\theta_\mathrm{L}/(1 - \sin\theta_\mathrm{L})] \quad (2)$$

where $[\,\cdot\,]$ is the integer part of the term. Obviously, (2) is independent of the wavelength and of the grating period. For fixed Littrow angle θ_L it thus defines a unique grating with period d according to the Littrow condition $d = m\lambda/(2\sin\theta_\mathrm{L})$ with $m = L$ and fixed λ.

DGaO Proceedings 2012 - http://www.dgao-proceedings.de - ISSN: 1614-8436 - urn:nbn:de:0287-2012-B023-8

5 Explanation

A really convincing explanation for perfect blazing is given in [3] as degenerate four-wave interferences between the incident and diffracted waves being parallel but counterpropagating together with two reflecting waves at the two facets of the echelle grating. This leads to a more general formula for perfect blazing by defining a relation between three integers M, N, and L and the blaze angle α_b. While M and N represent the integer numbers of interferences on the two echelle facets, L is the well known Littrow order.

6 Examples

Two more examples are added to the ones in [1].

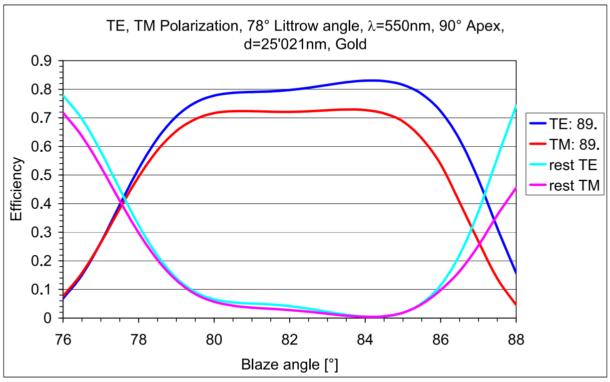

Fig. 1 *Perfect blazing for a gold grating at* $\lambda = 550$ *nm.*

In Fig. 1 perfect blazing is shown for a gold echelle grating in the visual spectral range at $\lambda = 550$ nm. The optimal blaze angle is again $\alpha_\mathrm{b} = 84°$ for a Littrow angle of $\theta_\mathrm{L} = 78°$ as shown in [1].

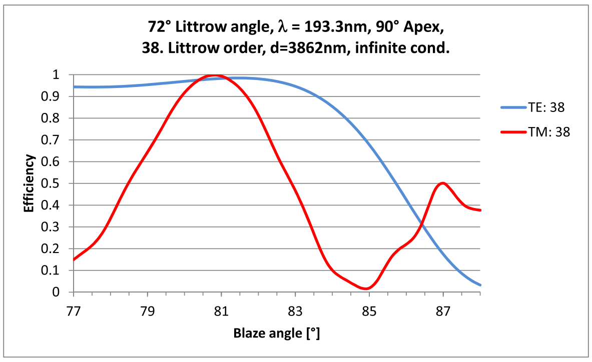

Fig. 2 *Perfect blazing for a Littrow angle of* $\theta_\mathrm{L} = 72°$*.*

A Littrow angle of $\theta_\mathrm{L} = 72°$ with the special Littrow order $L = 38$ according to (2) is used in Fig. 2 with an echelle grating of infinite conductivity. The optimal blaze angle for perfect blazing is around $\alpha_\mathrm{b} = 81°$, if taken from the simulation curves. And really, equation (1) gives the same result.

7 Fabrication

One of the main preconditions for perfect blazing with echelle gratings is a $90°$ apex angle. Hence it is very important to fulfill this condition also during fabrication. It should be advantageous to use plane parallel glass plates with the thickness of the plates being about the period of the grating, Chris Velzel suggested in the discussion on the fabrication of echelle gratings with the property of perfect blazing [4]. These plates immediately fulfill the condition of a $90°$ apex angle.

Interestingly, an author's colleague expressed the same idea some weeks before, to use plane parallel plates [5], in our in-house discussion on fabrication of the echelle gratings with the desired properties.

8 Acknowledgement

The author thanks R. Güther for inspiring discussions concerning the explanation of the perfect blazing effect. Additionally, the author thanks Nils Haverkamp and Eduard Schmidt for interesting discussions on the fabrication of echelle gratings with perfect blazing properties.

References

[1] B. H. Kleemann, "Perfect blazing with echelle gratings in TE and TM polarization," *Optics Letters* **37**(6), 1002–1004 (2012).

[2] H. J. Rostalski, Carl Zeiss SMT GmbH, *Private communication in the discussion to publication [1]*, May 10th 2012.

[3] R. Güther, "Degenerate four-wave interferences and perfect blaze," 113th Conference and Annual Meeting of the DGaO, Eindhoven (The Netherlands), p. P50 (2012). URL `http://www.dgao-proceedings.de`

[4] Chris Velzel, Veco b.v., *Public communication as Session Chair in the discussion to the talk B23 "Perfect blazing with echelle gratings in Littrow mount" by B. H. Kleemann on fabrication issues*, 113th Conference and Annual Meeting of the DGaO, Eindhoven (The Netherlands), May 31st 2012.

[5] Eduard Schmidt, Carl Zeiss AG, Corporate Research and Technology, *Private communication in the discussion to the talk "Perfect blazing with echelle gratings in Littrow mount" by B. H. Kleemann on fabrication issues*, Carl Zeiss AG internal information meeting, Oberkochen (Germany), May 4th 2012.