Reflective high efficiency binary gratings: finite conductivity

Bernd H. Kleemann

Central Research and Technology, Carl Zeiss, D-73446 Oberkochen

mailto:b.kleemann@zeiss.de

Finite conductivity near IR high efficiency binary grating parameter ranges are significantly reduced compared to results for infinite conductivity. Nevertheless, in non-Littrow applications it can happen that the angular ranges are greater for finite conductivity. Therefore, it is absolutely necessary to include rigorous efficiency optimisation into the geometrical optical design process.

1 Introduction

From [1] and [2] it is well known that with binary gratings in Littrow mount one can reach high efficiency – usually more than 90% also in reflection. In [2] this has been shown for the case of infinite conductivity (ic) being relevant mainly in the IR region. The present investigation shows the dependencies of the TM-efficiency in -1. order near Littrow-reflection mount of binary gold gratings for a semiconductor laser diode with a wavelength of λ = 807nm on several grating profile parameters. Such parameters are the ratios d/λ, h/λ, w/d, with grating period d, profile depth h, pulse width w of the binary structure as well as the tilt angle α of the sidewalls of trapezoidal profiles, if no rectangular profile is reached, and the incidence angle θ, if no Littrow mount is considered. Some parts of this investigation have been already published in [3], [4]. Littrow mount in –1. order is characterised by the condition $\sin\theta = \lambda/(2d)$. The IESMP is used for all presented calculations, a fast boundary integral equation method [3] well known as a reference method. Binary gratings are investigated in much more publications than cited above. An example of recent results on this type of grating is [5].

2 Maximal reachable TM-efficiency

Maximal TM-efficiency of more than 90% can be reached for $d/\lambda < 1.46$. In most cases a pulse width between w = 0.5d and w = 0.6d is optimal. For $1.35 < d/\lambda < 1.46$, w = 0.4d is better. The d/λ- and w/d-region of maximal efficiency is significantly smaller for λ = 807nm than for infinite conductivity [4]. The possibility to reach more than 90% TM-efficiency for $d/\lambda > 1.1$ is reduced to about ½ of the pulse widths known from infinite conductivity. Even for smaller periods the w/d interval is rarely greater than ¾ of the one for infinite conductivity.

The coincidence between finite and infinite conductivity forecast for pulse width ratio w/d tolerance reaching > 90% TM-efficiency is between ¾ and 1/3 of the tolerance for infinite conductivity for $d/\lambda < 1.15$. For greater periods d the forecast for pulse width ratio w/d tolerance is very bad.

Maximal efficiency is reached for different profile depths as given in figure 1. Optimal profile height h for maximal TM-efficiency greater 90% for finite conductivity is modified compared with infinite conductivity. The interval of greater height is shifted to smaller periods and it is increased for pulse widths w >= 0.5d. Additionally, the quasi-constant infinite conductivity profile height for pulse widths w >= 0.6d is changed into a quasi-constant two heights state as one can see in the figure below.

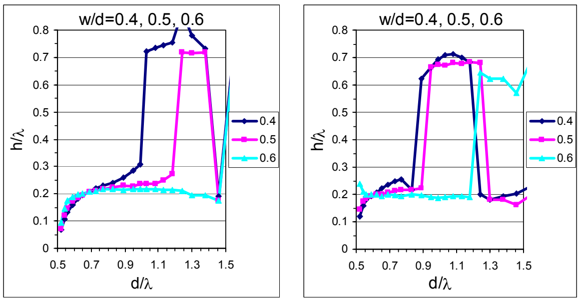

Abb. 1 *Profile height h for maximal TM-efficiency in Littrow-mount. Left: infinite conductivity, Right: finite conductivity for gold at 807nm (n = 0.1819 + i 5.2016).*

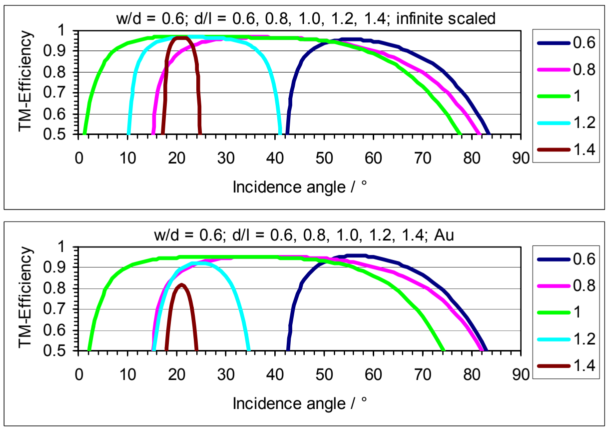

Abb. 2 *Comparison of incidence angle tolerance between infinite conductivity (top) and 807nm (bottom) for w/d=0.6.*

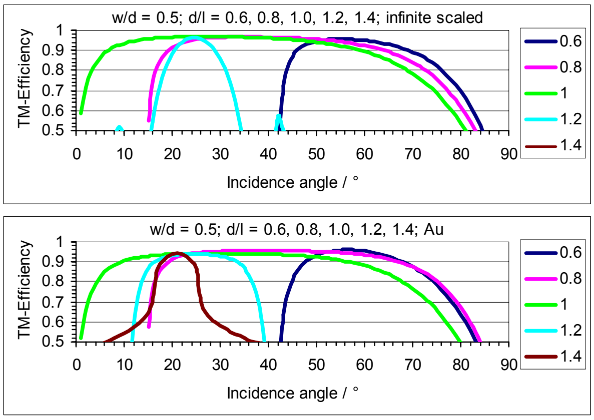

Abb. 3 *Comparison of incidence angle tolerance between infinite conductivity (top) and 807nm (bottom) for w/d=0.5.*

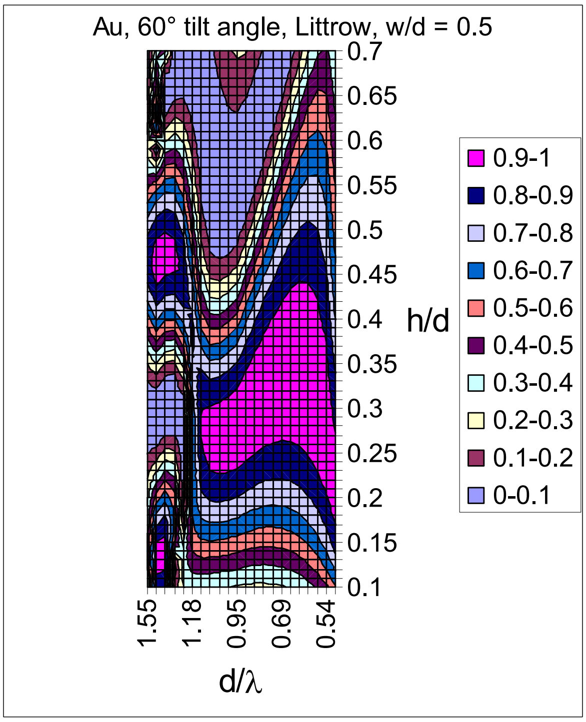

Abb. 4 *TM-efficiency of a trapezoidal profile with 60° sidewall tilt angle and a pulse width ratio w/d=0.5 at h/2.*

3 Incidence angle tolerance

High efficiency is possible to reach also in non-Littrow mountings (cf. figures 2 and 3). Angle tolerance is biggest for d/λ=1. Deviations from that value lead to smaller angle tolerance ranges. In most cases angle tolerance is weakly decreased by finite conductivity. Nevertheless, differing examples exist: Angle tolerance is reduced to about 1/3 of that for infinite conductivity for d/λ=1.2 and w/d=0.6 (figure 2). There is even no possibility to reach 90% efficiency in the real conductivity case in contrast to ic for d/λ=1.4 and w/d=0.6. On the other hand, angle tolerance is doubled compared to the infinite conductivity range if w=0.5d and d/λ=1.2 (figure 3). Additionally, surprisingly high TM-efficiency > 90% can be reached in real conductivity for w/d=0.5, d/λ=1.4, whereas ic efficiency is below 50% in that case! This demonstrates the fact that real conductivity modifies the parameter ranges for high efficiency rather than to reduce it only. Angle tolerance is significantly influenced for smaller pulse widths w =< 0.4d.

4 Trapezoidal profiles

Trapezoidal sidewall tilts deviating from 90° are mostly compensated by slightly different profile parameters (pulse width w, profile height h).

TM-efficiency can be positively influenced using e.g. 60° tilt angle. Only a weak improvement is observed for w=0.6d. On the other hand, the period range leading to maximal TM-efficiency at small profile heights (around 0.2λ) is extended from d < 0.9λ to d < 1.15λ for w=0.5d (figure 4) and from d < 0.7λ to d < 1.0λ for w = 0.4d.

5 Summary

Finite conductivity has a substantial influence in both, the NIR and VIS spectrum, compared to infinite conductivity, because of significant parameter range modifications for high efficiency binary and trapezoidal profiles in Littrow and non-Littrow applications. Therefore, the efficiency optimisation of reflective diffractive optical elements with such profiles has to be done in close connection with the geometrical optical design. The best way to do so is the full integration of rigorous efficiency calculations into the geometrical optical design software.

References

[1] E. G. Loewen, M. Nevière, and D. Maystre, „Efficiency optimization of rectangular groove gratings for use in the visible and IR regions“ in *Appl. Opt.* **18**: 2262-66 (1979)

[2] E. Noponen, J. Turunen, „Efficiency optimization of rectangular groove gratings for use in the visible and IR regions“ in *J. Opt. Soc. Am. A* **11**: 1097-1109 (1984)

[3] B. H. Kleemann, *Elektromagnetische Analyse von Oberflächengittern von IR bis XUV mittels einer parametrisierten Randintegralmethode: Theorie, Vergleich und Anwendungen,* Mensch und Buch, Berlin (2003), *http://www.familiekleemann.de.vu/die_eltern.htm*

[4] B. H. Kleemann: “Binary reflective high-frequency-carrier diffractive optical elements: finite conductivity” in *EOS TM Digest Series on Diffractive Optics 2003*, Z. J. Laczik (Ed.), Institute of Physics Publishing: 18-19 (2003)

[5] I. Richter, Z. Ryzi, and P. Fiala, „Efficiency optimization of rectangular groove gratings for use in the visible and IR regions“ in *J. mod. Opt.* **45**: 1335 (1998)