Transmission gratings for beam sampling and beam splitting

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Transmission gratings have rarely been used for beam sampling because they require special properties from dielectric overcoatings, which, to the best of our knowledge, are described here for the first time. Although such gratings are often used as beam splitters, their nature can be modified along the same principles with thin metal coatings, which are described.

Key words: Transmission gratings, beam sampling.

1. Introduction

There are two applications for transmission gratings that have not been seriously considered because of the special properties that are required. One is for beam sampling, in which the reflection of the input beam must be less than 1% and at the same time the amount of light going into the sampling direction must be adjustable from 1% to 0.01%. A buried grating design is proposed for this purpose.

The second application is quite different but follows the same approach to a solution. It is a hybrid transmission–reflection grating in which one beam is transmitted undispersed and the second is diffracted in reflection.

2. Beam Sampling

Beam-sampling gratings have found wide use for accurate wave-front sampling of high-power laser beams without significantly influencing output. Normally this is done with very lightly modulated mirror surfaces, i.e., in reflection. Although this allows the diffracted fraction to be made as low as desired (10^{-3} to 10^{-6}) this calls for modulation depths of 10^{-2} to 10^{-4}.[1] It is difficult to prepare such low depths of modulation with adequate uniformity and repeatability. An alternative approach is to use a transmission grating, but then it becomes critical to reduce the zero-order specular reflection to a near-zero level. The normal approach to reducing reflection is with dielectric quarter-wave stacks. However, this is not suitable in this case because their combination with a grating periodicity inevitably leads to resonance anomalies caused by waveguide mode excitation in the multilayer structure.[2]

The suggestion made here is to reduce the zero-order reflection by increasing the groove depth modulation, although, as is shown below, this increases the amount of light in the first-order transmitted sampling beams. A typical example is given in Fig. 2 below, where the efficiencies in the zeroth reflected and plus or minus first orders transmitted are presented as a function of groove depth for the grating shown in Fig. 1. The grating period is chosen so that there is only one possible reflected order (the specular or zero order), whereas in transmission there are three orders. The thickness of the single antireflection coating is chosen to minimize reflection. Because the optical index is lower than that of the substrate, there will be no waveguide modes. Although reflection at a dielectric coated plane surface cannot be reduced to less than 1.5% with a single layer, it can be practically zeroed by a correct choice of groove depth. However, the two first-order transmitted beams will have an efficiency of ~1.5% each; i.e., energy is transferred from the zero reflected order to the first orders in transmission.

Because 1.5% is much too high for most beam-sampling applications, it becomes necessary to look for a way out. The solution is to cover the grating surface with the same material as the substrate, as shown in Fig. 3. Although evaporation of a sufficiently thick glass layer is possible, it is not the best

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Received 20 July 1995; revised manuscript received 31 July 1995.
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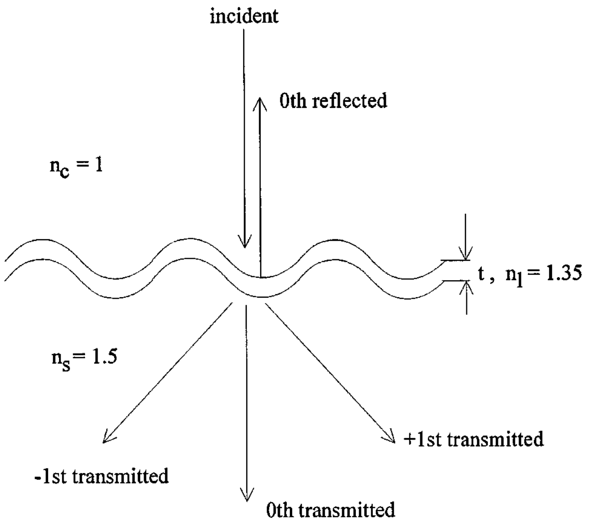


Fig. 1. Schematic representation of a dielectric grating covered with a thin layer of lower-index material to reduce reflection.

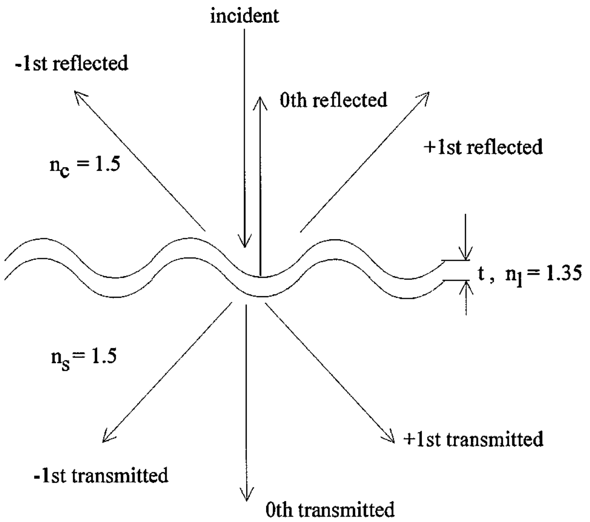


Fig. 3. Same as Fig. 1, but with a cladding made of the same material as the substrate.

solution. Standard replica transmission gratings point the way to such a completely buried grating. Although this cladding increases the number of orders that propagate in the cladding, the total amount diffracted into the nonspecular orders is well below 1%. A correct choice for the middle layer thickness also serves to reduce the efficiency of the specular reflected order. An important point is that this behavior does not call for delicate ultralow modulations. Figure 4 presents the angular dependence of efficiencies for the grating given in Fig. 3 for a groove depth-to-period ratio of 10%. Because of groove symmetry, the plus first order is symmetrical to the minus first order with respect to normal incidence. A total of only 0.16% of the incident energy is diffracted outside the specular transmitted order. For light to be coupled into and out of the system, both sides of the device can be covered with multilayer antireflection layers. These layers are separated from the grating by a comparatively large distance (several micrometers are sufficient) so that no evanescent orders can excite waveguide modes.

The performance of this completely buried grating is preserved despite the increase in the number of diffracted orders. By varying the groove depth and the groove shape, one can vary the relative intensity of the diffracted beams, and by varying the thickness

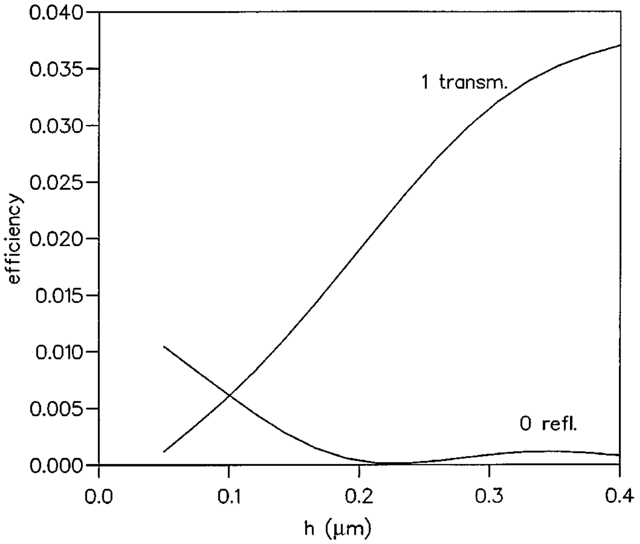


Fig. 2. Efficiency of the grating shown in Fig. 1 in the plus or minus first transmitted and zeroth reflected order (TM polarization, wavelength of 0.6328 μm, and normal incidence). Layer thickness $t = 0.14$ μm. The refractive indices are indicated in Fig. 1, and the grating period is 0.5 μm. Only the zeroth reflected order propagates in the cladding, whereas in the substrate there are three orders.

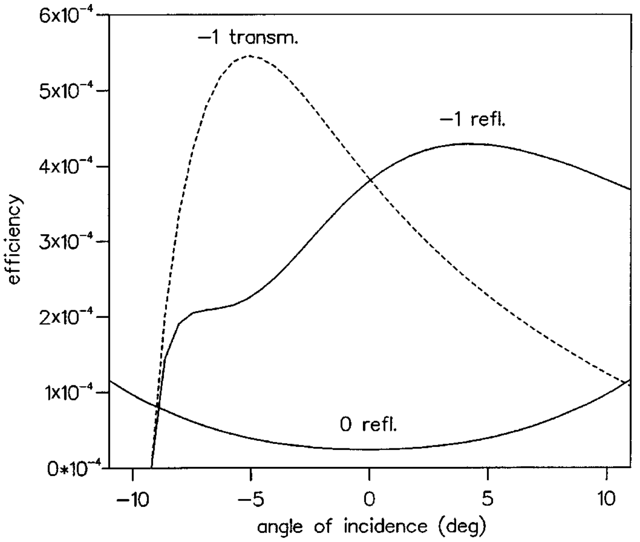
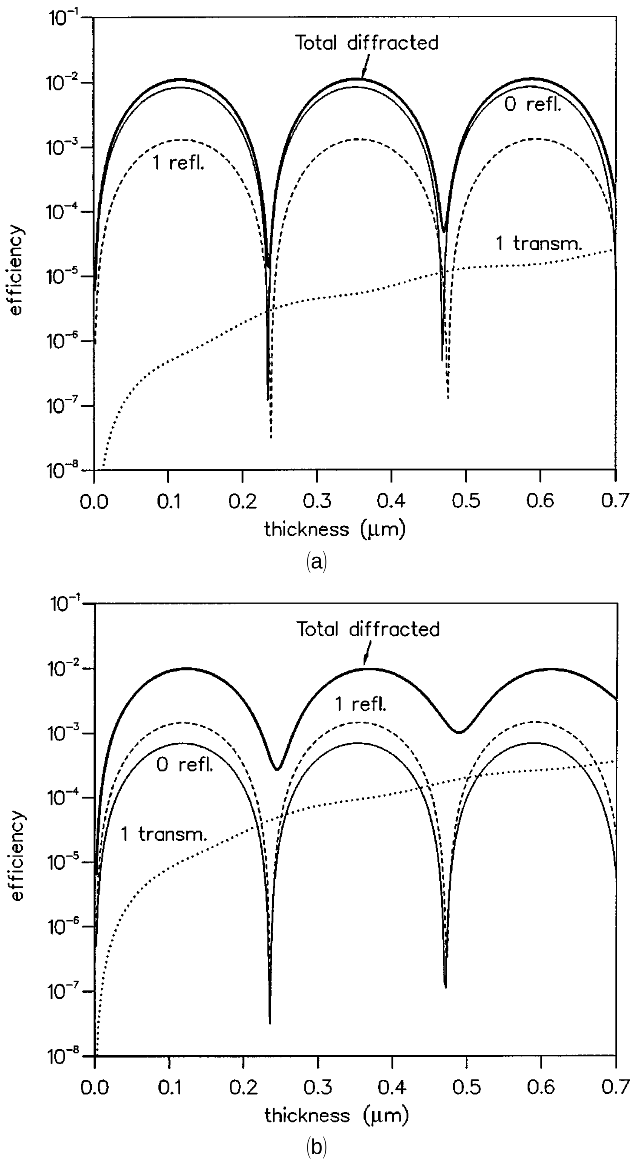


Fig. 4. Angular dependence of all efficiencies other than the specular (zero) transmitted order, for the grating shown in Fig. 3. The period is 0.5 μm, the groove depth is 0.05 μm, and the wavelength is 0.6328 μm (TM case). The wavelength-to-period ratio and the refractive indices of Fig. 3 permit three propagating orders in cladding (Layer thickness $t = 0.23$ μm).



(a)

(b)

Fig. 5. Efficiency of a grating with the sinusoidal groove profile and indices of Fig. 3: A wavelength of 0.6328 μm and a period of 2 μm permits 9 orders in the substrate and the cladding. Total light diffracted besides the specular transmitted order, the efficiencies in the first reflected and transmitted orders, and the zeroth reflected order as a function of layer thickness t (TE polarization). Groove depth: (a) 0.05 μm, (b) 0.2 μm.

of the intermediate layer, one can vary the the total amount of light scattered out of the specular transmitted order from 1% to less than 0.01% (Fig. 5).

3. Beam Splitting

The same concept of covering a thin corrugated layer with the same material as the substrate can be used to split an incident beam into two orders: a specular (zero-order) transmitted beam and a dispersive (diffracted) reflected one with comparable efficiencies. In this case it becomes necessary to make use of a semitransparent metallic layer. Its thickness will determine the ratio between the reflected and transmitted order efficiencies. Such a grating might be used, for example, as an exit semitransparent mirror that has dispersive properties in reflection. The groove profile and depth is determined by the requirement that the same grating with sufficiently thick metallic layer has to blaze into the corresponding reflection order. A fine-pitch sinusoidal grating with 40% modulation can blaze into the minus first order

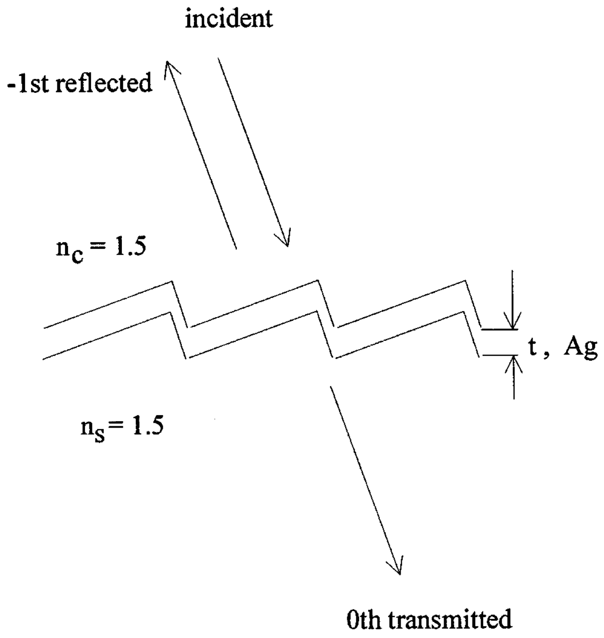


Fig. 6. Schematic representation of a blazed grating consisting of a semitransparent silver echelette grating, embossed inside a dielectric material. Incidence is perpendicular to the large facet, and the period is chosen to ensure a minus first order Littrow mount.

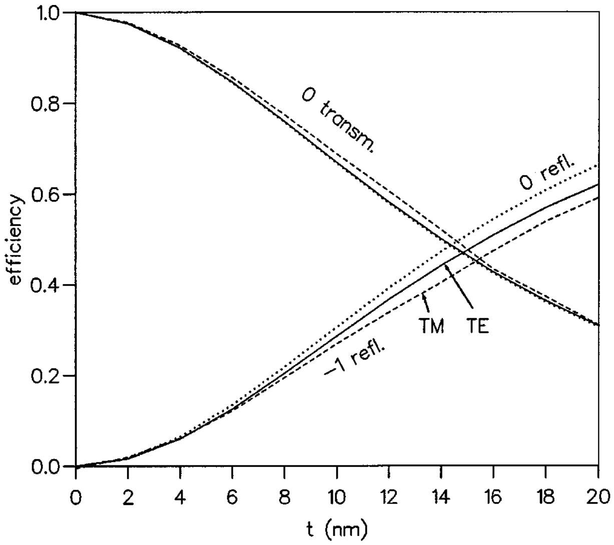


Fig. 7. Efficiency as a function of the silver layer thickness t for the blazed grating presented in Fig. 6, with a 3° blaze angle, 90° apex angle, and a period of 4.030 μm, at a wavelength of 0.6328 μm. Efficiencies of minus first reflected and zeroth transmitted orders are compared with what they would be on a plane uncorrugated surface (labeled 0 refl. and 0 transm., respectively) to show how little light goes to the other diffracted orders.

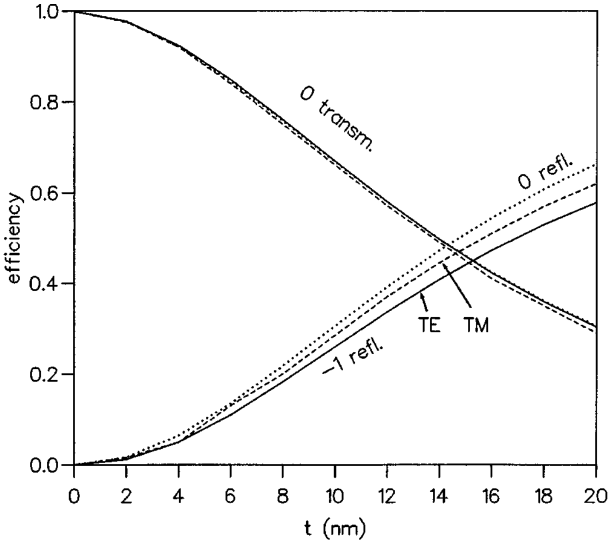


Fig. 8. Same as Fig. 7, but with a 7.5° blaze angle and a period of 1.616 μm.

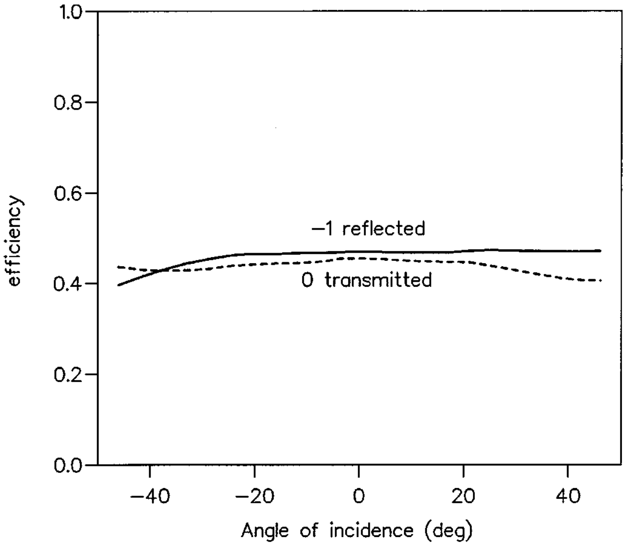


Fig. 9. Angular dependence of the efficiency of the grating from Fig. 8 in TE polarization. Blaze angle, 7.5 deg.

in TM polarization (electric vector perpendicular to the grooves), because in the TE plane of polarization the efficiency would be quite low.[3] A more likely case would be to use a relatively coarse echelette grating, in which polarization properties are almost negligible. Typical examples are presented in Figs. 7 and 8 below for two blaze angles (3° and 7.5°, respectively) of the diffraction grating given in Fig. 6, with a silver middle layer. Depending on the thickness, the ratio between the specular transmitted order and the diffracted minus first order can be controlled. It must be noted that the grating with a 3° blaze angle supports 19 reflected and 19 transmitted orders, and yet the entire amount that fails to go into the two strongest orders is less than 2.5%. The fact that this effect is not associated with any resonant behavior permits performance that is affected only slightly by changes in the angle of incidence (Fig. 9).

4. Conclusion

It is shown that buried beam-sampling transmission gratings can be constructed to provide the necessary low sampling efficiency, but without having to depend on delicate low modulations that go with corresponding reflection grating approaches. The same philosophy can be used to design an entirely different optic, namely a transmission grating beam splitter that allows one beam to be transmitted in zero order while a second beam is diffracted in reflection at an angle that can be specified over a wide range. There is little light lost to other orders, except that if polarization effects are to be avoided, the angle cannot be too large.

References

1. E. Loewen, M. Neviere, and D. Maystre, “Optimal design for beam sampling mirrors,”Appl. Opt. **15,** 2937–2939 (1976).
2. L. Mashev and E. Popov, “Diffraction efficiency anomalies of multilayer dielectric gratings,” Opt. Commun. **51,** 131–137 (1984).
3. D. Maystre, M. Neviere, and R. Petit, “Experimental verification and applications of the theory,” in *Electromagnetic Theory of Gratings,* R. Petit, ed. (Springer, New York, 1980), Chap. 6.