AN INFRARED THERMAL SOURCE WITH HIGH DIRECTIVITY AND UNUSUAL SPECTRAL PROPERTIES

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INTRODUCTION

It is well known that the topography of a surface has a strong influence on its radiative properties[1,2]. It will be shown, in this paper, that ruling a lamellar grating - specifically designed - on a flat surface allows to produce a highly directional source that behaves like an antenna. We study the spectral and directional reflectivity and emissivity of a Silicon Carbide (SiC) lamellar grating, both theoretically and experimentally. We show that, due to the excitation of resonant surface waves, the radiative properties of a SiC grating are very unusual. Such a source exhibits a high degree of spatial coherence (i.e. directivity)[3] and temporal coherence (i.e. quasi-monochromatic emission)[4]. Our theoretical calculations are in very good agreement with experimental results.

THEORETICAL CALCULATIONS

For the calculations, we use the formalism developed by Sentenac and Greffet[5] to study diffraction by gratings of arbitrary profile. This is an exact electromagnetic method based on an volume integral formulation of Maxwell's equations. It enables us to calculate the directional and spectral polarized reflectivity of the grating. The geometry of the grating used for calculations and experiments is depicted in Fig. 1.

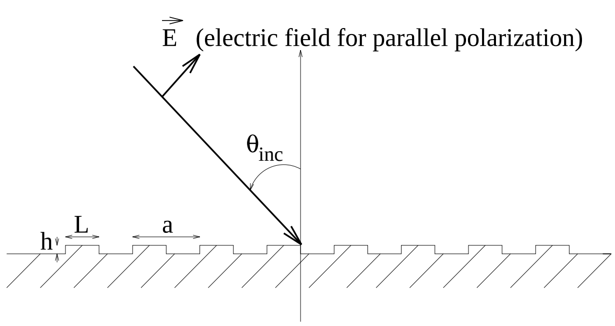

Figure 1. Geometry of the SiC grating used for calculations and experiments: $L = 3.12\,\mu$m, $h = 0.28\,\mu$m and $a = 6.25\,\mu$m. For parallel polarization, the electric field is in the plane of incidence.

Figure 2 shows the spectral reflectivity, for parallel polarization (see Fig. 1), of the grating for three angles of incidence.

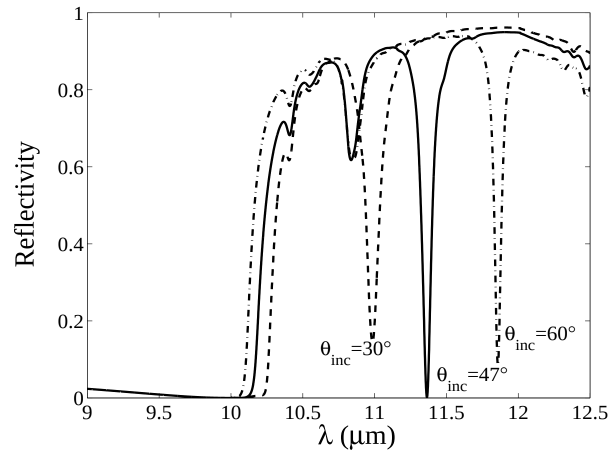

Figure 2. Spectral reflectivity (for parallel polarization) of the SiC grating versus wavelength for three angles of incidence.

It is seen that the reflectivity displays sharp dips for particular wavelengths. For $\theta_{inc} = 47°$, reflectivity is smaller than 0.2% at $\lambda = 11.36\,\mu$m. We must notice that the grating parameters were optimized to achieve this very small value. The physical origin of these peaks is the following: the incident light on the grating is coupled to resonant surface waves propagating along the interface. These waves are absorbed by Joule's effect, so that the reflectivity becomes very small. Furthermore, since this coupling is a resonant phenomenon, it appears only for particular angles of incidence and particular wavelengths. Moreover, the surface waves are excited only for parallel polarization. Note that, due to Kirchoff's law, such a grating exhibits sharp peaks in its emission spectrum for particular wavelengths. In the same way, at a given wavelength, the directional emissivity should also display a narrow lobe for a well-defined angle. This is a very unusual behavior for a thermal source.

COMPARISON WITH EXPERIMENTAL MEASUREMENTS

In this part, we present experimental results obtained with the same grating as above. Fig. 3 shows the predicted and measured angular dependence of the directional emissivity of the SiC grating at $\lambda = 11.36\,\mu$m and for the parallel polarization.

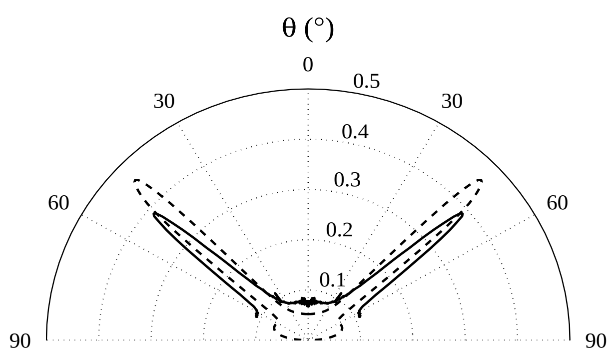

Figure 3. Predicted (dashed line) and measured (solid line) directional emissivity (for parallel polarization) of the SiC grating at $\lambda = 11.36\,\mu$m.

Note that our simulations include the finite spatial and spectral resolution of the experimental setup.

The predicted behaviour is demonstrated experimentally: the emissivity displays directional peaks at a given wavelength. This thermal source behaves as an infrared antenna ! However, a difference in the peak position and intensity is visible in Fig. 3. It comes from the temperature dependence of the index of refraction, that we cannot reproduce theoretically. In fact, we made simulations at $T = 300$ K, but measurements at $T = 500$ K. We must emphasize that this type of thermal source has a spectrum that depends strongly on the angle of emission. To our knowledge, this is the first example of a natural source displaying this effect, first predicted by Wolf [6].
In Fig. 4, we present a comparison between calculated and measured reflectivity of the SiC grating for two angles of incidence, $30°$ and $47°$, and for parallel polarization. Note that, in this case, the reflectivity measurements are performed at $T = 300$ K, so that our calculation correctly reproduces the peaks position and intensity, even for the resonant wavelength.

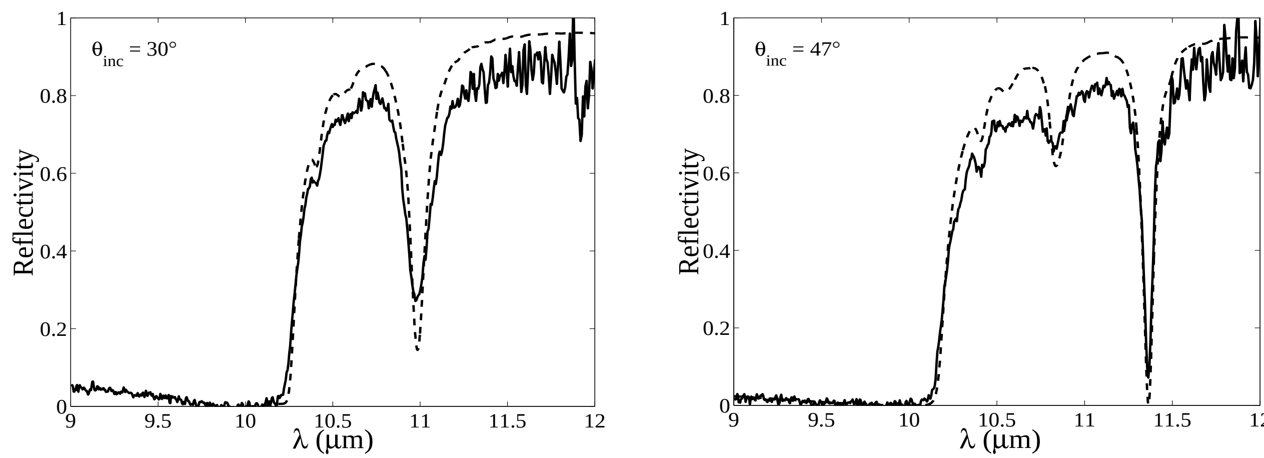

Figure 4. Calculated (dashed line) and measured (solid line) spectral reflectivity (for parallel polarization) of the SiC grating at $\theta_{inc} = 30°$ (left) and $\theta_{inc} = 47°$ (right).

These results could have broad applications. Quasi-monochromatic sources with high directivity can be produced by designing a particular profile on a material supporting resonant surfaces waves (e.g. glass in the IR). Furthermore, radiative properties of surfaces can be changed from a reflecting to an absorbing behaviour.

REFERENCES

1. Hesketh, P.J., Zemel, J.N., and Gebhart, B., Organ pipe radiant modes of periodic micromachined silicon surfaces, *Nature*, (London), Vol. 324, pp 549-551, 1986 ;

2. Le Gall, J., Olivier, M. and Greffet, J.J., Experimental and theoretical study of reflection and coherent thermal emission by a SiC grating supporting a surface-phonon polariton, *Phys. Rev. B*, Vol. 55, No. 15, pp 10105-10114, 1997.

3. Carminati, R. and Greffet, J.J., Near-field effects in spatial coherence of thermal sources, *Phys. Rev. Lett.*, Vol. 82, No. 8, pp 1660-1663, 1999.

4. Shchegrov, A.V., Joulain, K., Carminati, R., and Greffet, J.J., Near-field spectral effects due to electromagnetic surface excitations, *Phys. Rev. Lett.*, Vol. 85, No. 7, pp 1548-1551, 2000.

5. Sentenac, A. and Greffet, J.J., Scattering by deep inhomogeneous gratings, *J. Opt. Soc. Am. A*, Vol. 9, No. 6, pp 996-1006, 1992.

6. Wolf, E., Invariance of the spectrum of light on propagation, *Phys. Rev. Lett.*, Vol. 56, No. 13, pp 1370-1372, 1986.