AN INFRARED THERMAL SOURCE WITH HIGH DIRECTIVITY AND PECULIAR 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. Then, designing a particular surface profile on a thermal source can be used to modify its emissivity and reflectivity. Moreover, if the surface can support resonant surface waves, these properties are also changed. This phenomenon was first reported on a doped-silicon grating[1] which supports surface-plasmon polaritons: emissivity displays peaks in well-defined directions and at particular frequencies.

In this paper, we study the spectral and directional reflectivity and emissivity of a Silicon Carbide (SiC) lamellar grating, both theoretically and experimentally. This material supports surface-phonon polaritons in the infrared region near $10\,\mu$m. We show that, due to the excitation of surface-phonon polaritons, the radiative properties of a SiC grating are very peculiar. Such a source exhibits a high degree of spatial coherence (directivity)[2] and temporal coherence (quasi-monochromatic emission)[3]. Our theoretical calculations are in very good agreement with the experiments and previous results[4].

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.

Fig. 2 shows the spectral reflectivity (for parallel polarization, see Fig. 1) of the grating for three angles of incidence. It can be seen that reflectivity displays sharp dips for particular wavelengths. For $\theta_{inc} = 47°$, reflectivity is smaller than 0.2% at $\lambda = 11.36\,\mu$m. The physical origin of these peaks is the following: the incident light on the grating is coupled to the surface-phonon polariton (SPP) surface waves propagating along the interface (see Fig. 1). 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-phonon polaritons 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 directions. 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.

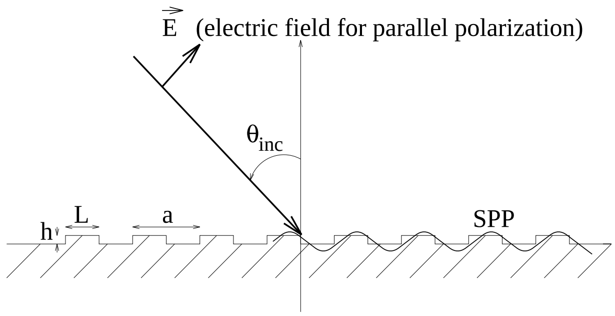

Figure 1. Geometry of the SiC grating used for calculations and experiments: $L = 3.12\,\mu$m, $h = 0.28\,\mu$m and $a = 6.25\,\mu$m.

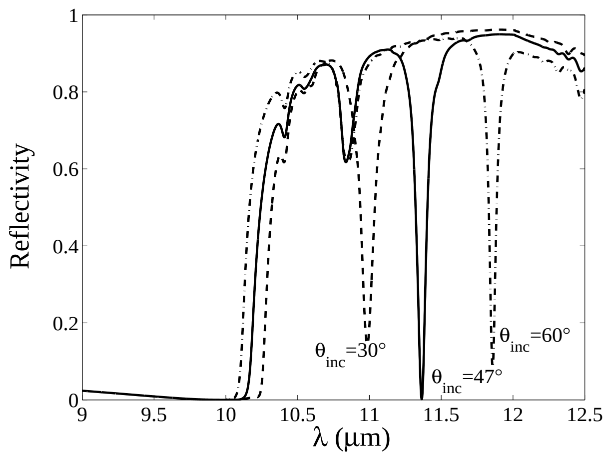

Figure 2. Directional reflectivity (for parallel polarization) of the SiC grating versus wavelength for three angles of incidence.

COMPARISON WITH EXPERIMENTAL MEASUREMENTS

In this part, we present the experimental results obtained with the same grating as above. Figure 3 shows the predicted and measured angular dependence of the emissivity of the SiC grating at $\lambda = 11.36\,\mu$m and for the parallel polarization. Note that in our simulations, we 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. Thus, 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 have been done at $T = 500$K. We must emphasize that this peculiar 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.

In Fig. 4, we present a comparison between calculated and measured reflectivity of the SiC grating for an angle of incidence of 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.

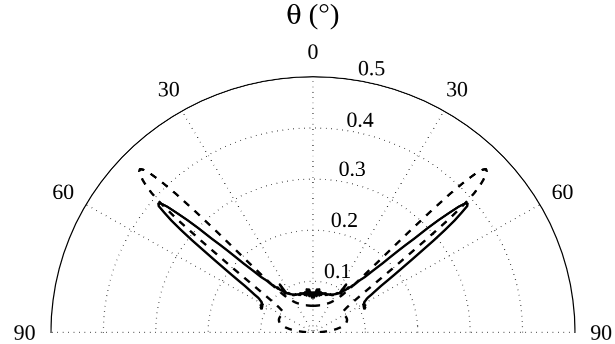

Figure 3. Predicted (dashed line) and measured (solid line) directional emissivity (for parallel polarization) of the SiC grating at $\lambda = 11.36\,\mu$m.

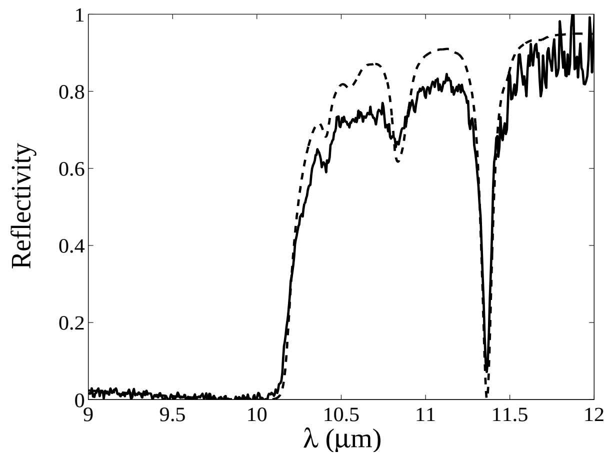

Figure 4. Calculated (dashed line) and measured (solid line) spectral reflectivity (for parallel polarization) of the SiC grating at $\theta_{inc} = 47°$.

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