RADIATIVE COHERENT THERMAL EMISSION BY MICROSTRUCTURED MATERIALS

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The emission of radiation by an antenna is usually substantially different form the emission of radiation by a thermal source. Different parts of an antenna emit waves that can interfere constructively in particular directions producing well-defined angular lobes. On the other hand, it is usually taken for granted that light spontaneously emitted by different points of a thermal source cannot interfere. Therefore, the emission of a thermal source cannot be directional. However, it has been shown recently by Carminati et al. [1] (1999) and Shchegrov et al. [2] (2000) that the electromagnetic field produced by a thermal source in the near field is enhanced by more than four orders of magnitude and is partially coherent. This paves the way for the construction of a thermal source that could radiate light within narrow angular lobes as an antenna instead of having the usual quasi lambertian angular behaviour. The purpose of this paper is to describe a thermal source that by combining this effect and microstructuring of an interface generates monochromatic and directional light in the far field, i.e. a partially coherent thermal source

In this article, we report theoretical calculations and experimental measurements demonstrating that it is indeed possible to build an infrared antenna by properly designing a microstructure on a polar material such as a semiconductor. Two types of thermal sources have been designed.

Firstly, a source able to radiate infrared light in a narrow solid angle when it is heated. The angular emission pattern of this source is shown in Fig. 1. It is seen that the emission pattern displays two narrow lobes very much like an antenna. This is a signature of its spatial coherence[3]. In order to obtain this result we have optimlized the design of the grating using rigorous numerical models of grating diffraction[4]. Another remarkable property of this source is that its emission spectrum depends on the observation direction. This property was first predicted by E. Wolf [5](1986) as a consequence of spatial correlations for random sources. This effect has been demonstrated experimentally for artificial secondary sources but had never been observed for direct thermal emission. Fig. 2 shows a theoretical emission spectrum of a microstructured sample of SiC at three different observation angles. The microstructure is a rectangular grating of period 6.25µm, height 0.285µm with a volume filling factor of 0.5. For each direction, the emission spectrum exhibits a narrow peak around a central frequency.

Secondly, a thermal source radiating infrared light isotropically at a single frequency. This source is not directional, does not exhibit the Wolf effect but radiates always at the same frequency whatever the observation angle is. It displays a quasimonochromatic peak in its emission spectrum in a region where a flat surface has a very low emissivity. Figure 3 shows the experimental thermal emission spectrum of a SiC sample on which a grating of period 3.00µm, height 0.5µm and volume filling factor 0.4. has been ruled. We observe that the emission spectrum in p-polarisation exhibits a peak whatever the angle of observation is whereas the peak does not exist for s-polarisation. This source is isotropic in a plane perpendicular to the grooves.

In conclusion, the understanding of the strong coherence properties of a planar source in the near field has enabled us to design far-field sources with specified emission properties. We have used numerical simulations to optimize the design of gratings that have emissivities dramatically different from plane surfaces. Enhancement of the emissivity by a factor of 20 can be obtained. Very narrow or very broad angular emission patterns have been demonstrated.

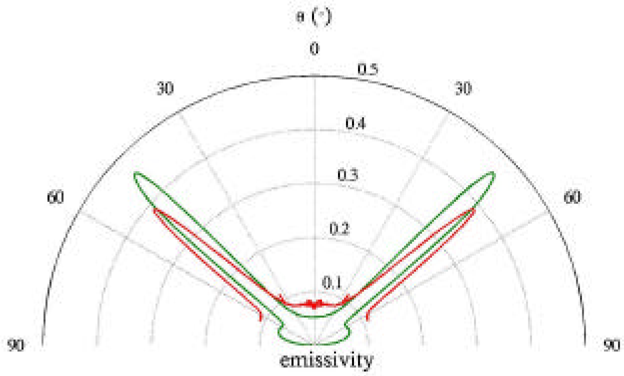

Figure 1. Comparison between the theoretical polar emission spectrum (in green) and the experimental polar emission spectrum (in red) for a wavelength λ=11.36µm. Calculations have been done using the optical properties at ambiant temperature whereas emission measurements were done at 500 °C. This is the reason of the discrepancy.

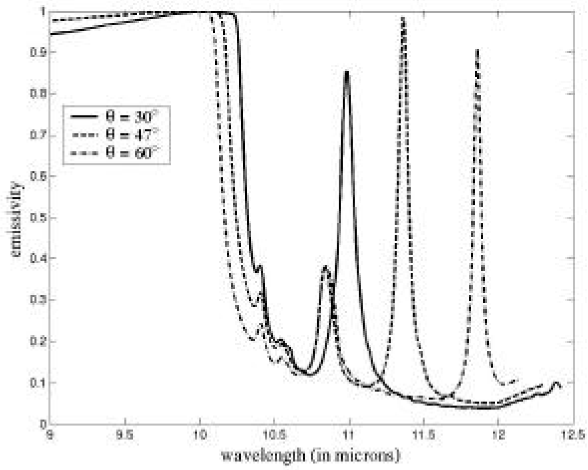

Figure 2. Theoretical emission spectrum of a microstructured sample of SiC at three different observation angles. The microstructure is a rectangular grating of period 6.25µm, height 0.285µm with a volume filling factor of 0.5. Note the strong emission peak centered on a direction that depends on the observation angle.

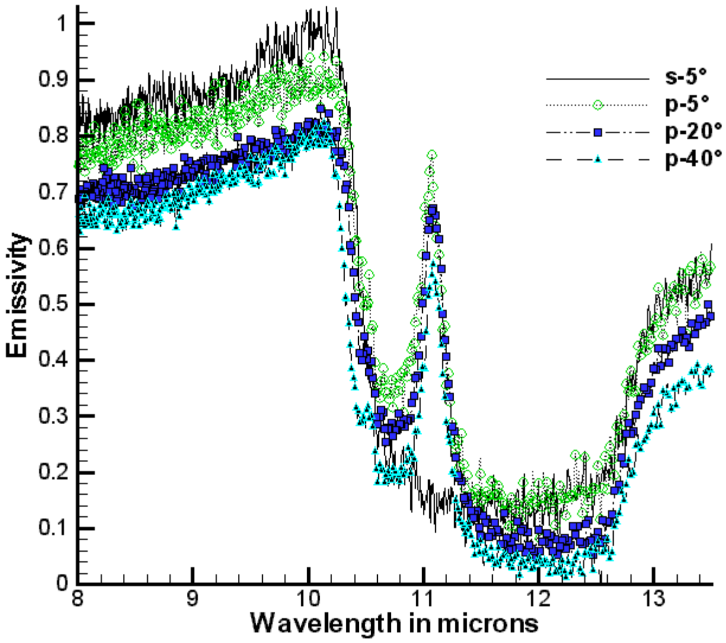

Figure 3. Experimental thermal emission spectrum of SiC sample on which a grating of period 3.00µm, height 0.5µm and volume filling factor 0.4 has been ruled. Note that for this period, the emission peak does not depend on the observation angle. The label p or s denote the polarisation of the emission signal whereas the angles denote the direction (from the normal of the sample) in which the spectrum is taken.

REFERENCES

1. Carminati R., Greffet J.J. Near-field effects in spatial coherence of thermal sources. Phys. Rev. Lett. 82, (1999) 1660-1663.
2. Shchegrov A., Joulain K., Carminati R. and Greffet J.J. Near-field spectral effects due to electromagnetic surface excitations. Phys.Rev.Lett**.** 85**,** (2000) 1548-15451.
3. J.-J. Greffet, R. Carminati, K. Joulain, J.-P. Mulet, S.Mainguy and Y.Chen, Coherent emission of thermal sources, to be published in Nature.
4. A. Sentenac, J.J. Greffet, Scattering by deep inhomogeneous gratings, J. Opt. Soc. Am. A 9, 996-1006 (1992)
5. Wolf E. Invariance of the spectrum of light on propagation. Phys. Rev. Lett. 56, (1986) 1370-1373.