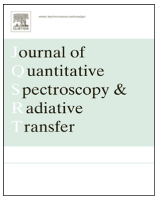
Journal of Quantitative Spectroscopy & Radiative Transfer 180 (2016) 29–38

Contents lists available at ScienceDirect

Journal of Quantitative Spectroscopy & Radiative Transfer

journal homepage: www.elsevier.com/locate/jqsrt



Temperature dependence of a microstructured SiC coherent thermal source

Armande Hervé [a,*], Jérémie Drévillon [a], Younès Ezzahri [a], Karl Joulain [a,*], Domingos De Sousa Meneses [b], Jean-Paul Hugonin [c]

[a] Institut Pprime, CNRS, Université de Poitiers, ISAE-ENSMA, F-86962 Futuroscope Chasseneuil, France
[b] CNRS-Conditions Extrêmes et Matériaux Haute Température et Irradiation, 1D, Av. de la Recherche Scientifique, F-45071 Orléans, France
[c] Institut d'optique, 2 Avenue Augustin Fresnel, 91127 Palaiseau, France

ARTICLE INFO

Article history:
Received 15 February 2016
Received in revised form
8 April 2016
Accepted 9 April 2016
Available online 19 April 2016

Keywords:
Thermal radiation
Coherent thermal source
SiC
Gratings
Dielectric function variation with temperature

ABSTRACT

By ruling a grating on a polar material that supports surface phonon–polaritons such as silicon carbide (SiC), it is possible to create directional and monochromatic thermal sources. So far, most of the studies have considered only materials with room temperature properties as the ones tabulated in Palik's handbooks. Recently, measurements have provided experimental data of the SiC dielectric function at different temperatures. Here we study, numerically, the effect of the temperature dependence of the dielectric function on the thermal emission of SiC gratings (1D grating, in a first approach), heated at different temperatures. When materials are heated, the position of the grating emissivity peak shifts towards higher wavelength values. A second consequence of the temperature dependence of optical properties is that room temperature designed gratings are not optimal for higher temperatures. However, by modifying the grating parameters, it is possible to find an emission peak, with a maximum of emissivity near 1, for each temperature. We tried first to catch some patterns in the emissivity variation. Then, we obtained a grating, which leads to an optimum emissivity for all available temperature data for SiC.

1. Introduction

Thermal sources are often considered as typical incoherent sources. However, it has been known for more than a decade that it is possible to create directional and monochromatic thermal sources by ruling a grating on a metal, supporting surface plasmon–polaritons, or a polar material which supports surface phonon–polaritons [SPP] such as SiC.

Many studies have been made exploiting the properties of gratings since then. A certain number of these studies are based on polar materials [1–4], but others use a metal grating, supporting surface plasmon–polaritons [5,6]. Most of the approaches have been developed in order to control the emission peak (peak wavelength, full width at half maximum (FWHM) for a given wavelength, etc.); it is often based on the optimization of a grating ruled on a bulk material [2,3,5,7,8], which is easier to manufacture with good homogeneity. Some of the approaches use however more complex structures mixing metal and polar materials [9,10]. Sources have been designed to achieve coherent thermal emission using gratings; with doped materials [11–14], cavities [15,16], photonic structures [17–21], and complex gratings [13,14,22,23]. Other periodic structures as waveguides [24] or multi-layered structures [25–28] can also be used. A two-dimensional grating ruled on a bulk material, supporting SPP, produces emission peaks for both polarizations transverse magnetic (TM) and transverse electric (TE), that makes it

---

* Corresponding authors.
E-mail addresses: armande.herve@univ-poitiers.fr (A. Hervé), karl.joulain@univ-poitiers.fr (K. Joulain).

http://dx.doi.org/10.1016/j.jqsrt.2016.04.007
0022-4073/

easily transferable to applications [4]. Others 2D-gratings can be found: metallic 2D-gratings [29,30] and complex 2D-gratings [9,10]. Some also use magnetic polaritons besides SPP [9,10,16,31].

It is worth mentioning that some works devoted to near-field radiative heat-transfer control with gratings. Biehs et al. studied near-field heat transfer between two gratings [32]. From another perspective, Didari and Menguc related the near-field thermal emission of corrugated surfaces and corrugated mesoporous SiC emitting layer separated by nano-gaps [33–36].

The control of thermal emission has already been explored in many different ways and many gratings have been designed. However, there are still many aspects to explore; the influence of the temperature is one of them. Indeed, so far, most of the studies have considered only materials with room temperature properties as the one tabulated in Palik's books. Experimental data of the temperature behavior of the dielectric function are very interesting as they allow us to study the behavior of the previously designed thermal sources with temperature. They can be very useful also to design new thermal sources at different temperatures in addition to room temperature. The knowledge of the emissivity of a device at different temperatures can also enhance the control of thermal emission. Finally, it permits adapting the numerical model to the experiments, because the measurement of the emissivity often needs to heat the sample in order to reach a sufficient level of emitting signal [1,2,37]. This is made possible here by SiC experimental optical data for different temperatures.

We first present how SiC coherent thermal sources and grating emission diagram are obtained: characteristics of the studied structure, experimental SiC dielectric function and the numerical method. We will show that the temperature dependence of SiC dielectric function influences significantly the emission of coherent thermal sources. Then we calculate the emissivity of gratings at different temperatures and in different configurations, with the experimental SiC optical data. We present a design of a narrow IR emitter for a large range of temperatures. Finally we discuss the obtained results in the light of surface wave physics and dispersion relation. These directional and monochromatic thermal sources can have many applications. For example, monochromatic thermal sources could be used as sources in thermo photovoltaic converters that would make very high efficiency conversion devices [26]. Another potential application is thermal rectification and more generally thermal management.

2. Properties of the studied structure

2.1. Grating and surface wave scattering

The studied structure is a one dimensional lamellar grating ruled on a SiC surface. The three parameters defining this grating are the period d, the depth h and the filling factor F (Fig. 1). Surface waves such as SPP or surface plasmon–polaritons are evanescent waves, so they exist only in the near field. Furthermore, these surface waves appear only in p-polarization (or TM). The domain of existence of these surface waves is defined by their dispersion relation. For an interface between vacuum and a material of dielectric function ϵ, the dispersion relation reads [38]:

$$\kappa_{//}^2 = \frac{\omega^2}{c^2}\frac{\epsilon(\omega)}{\epsilon(\omega)+1} \tag{1}$$

where $\kappa_{//}$ is the parallel component of the wave vector of the surface wave.

Surface waves are evanescent on both sides of the interface. Note that these modes are different from frustrated modes. One can show that for non-lossy materials, surface waves exist on the domain where $Re(\epsilon) < -1$. At room temperature without a grating as represented here (for the parallel wave vector fixed real, Fig. 2), we have a linear part, where $\kappa_{//} \approx \omega/c$, and an asymptotic part for the dispersion relation. The “light cone” is defined by $\omega = c\kappa_{//}$, depicted in the graph by the “light line”. When $\kappa_{//} < \omega/c$ the wavevector perpendicular to the interface is real whereas in the opposite case it is imaginary so that this wave is not propagating and is evanescent. Here the dispersion relation is outside this “light cone”. It is reflecting the fact that SPP only exist in the near-field.

However, when a grating is ruled at the source surface as in Fig. 3, it diffracts the surface wave and couples it to a propagative wave in the far-field. The emission angle and the wavelength are related to the dispersion relation by the usual grating law:

$$\frac{\omega}{c}\sin\,\theta = \kappa_{//} + p\frac{2\pi}{d} \tag{2}$$

with p an integer and d the period of the grating.

In the graph, because of the periodic grating structure, the dispersion relation is folded within the first Brillouin zone, i.e. $-\pi/d \le \kappa_{//} \le \pi/d$.

The parameters of the grating highly affect its emission. The change of the period d can modify the folding and thereby the peak wavenumber and the type of the coherent thermal source created:

- With a small period, as the folding occurs for $\kappa_{//} > \pi/d$, only the asymptotic part of the dispersion relation is folded in the light cone, so that emission will occur at fixed frequency and for all $\kappa_{//}$ in the light cone, i.e. all directions.
- With a higher period, the linear part is also folded in the light cone. So emission occurs for different frequencies that depend on $\kappa_{//}$, i.e. of the angle of emission.

The depth and the filling factor do not have a direct influence on the peak wavelength, but are important in order to optimize the coupling between surface waves and propagating waves.

2.2. SiC optical data

Optical properties of SiC can be found in [39]. But they are given only for room temperature and, as we are going to see, emissivity could change a lot with temperature. In this study, we have used SiC experimental optical data for different temperatures.

The dielectric function of SiC from 295 K to 1460 K has been extracted from measurements of the spectral emittance