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Surface Polariton: Resonance Frequency determined through Atomic Physics, Thermal Emissivity, Ellipsometry

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ABSTRACT

Surface modes govern near-field thermal emission, but knowing precisely their resonances remains a challenge in nanophotonics. For a given sapphire window, we find some disagreements between predictions derived from bulk thermal emissivity and Atom-Physics measurements. Ellipsometry looks a promising alternate method.

MOTS-CLEFS : *Surface mode, Thermal Emissivity, Casimir-Polder, Ellipsometry*

1. NEAR-FIELD THERMAL EMISSION AND SURFACE MODES

Thermal emission in the Near-field has been a topic of major interest since the turn of the century [1]. As compared to the universal blackbody emission; it is considerably by the coupling with evanescent modes of the emitting body enhanced for distances $\leq hc/kT$ (i.e. 5-50 μm). It can even become quasi-monochromatic in the extreme limit of near-field ($\ll hc/kT$), as solely governed by surface modes. Precise predictions would be naturally of interest for a variety of new applications, such as thermal diodes or thermal spectral lamp, but the predictions, which are material dependent, demand an accurate estimate of the frequency of surface modes. These modes can even evolve with temperature, and are sensitive to the crystallographic orientation of the material.

2. SOME EXPERIMENTAL DISAGREEMENTS BETWEEN A CASIMIR-POLDER ATOMIC SENSOR AND SURFACE MODES AS PREDICTED FROM BULK THERMAL EMISSIVITY

For an ideal planar interface between a bulk medium and vacuum, the surface response, from which surface modes can be deduced, and which is totally dominant in the extreme near-field regime, is governed by the complex value $S(\omega) = [\epsilon(\omega) - 1] / [\epsilon(\omega) + 1]$, where $\epsilon(\omega)$ is the relative dielectric permittivity of the material at frequency ω . This permittivity exhibits a temperature-dependence $\epsilon(\omega, T)$. A difficulty is that the resonance for $S(\omega, T)$ appears for $\epsilon(\omega, T) \sim -1$, in a range far away from any resonance for $\epsilon(\omega)$, where the material is moreover strongly absorbing -i.e. it is not an "optical window". The relative permittivity $\epsilon(\omega, T)$ is usually determined with experimental spectra of reflectivity (or equivalently, thermal emissivity) and an elaborate modelling, from which $S(\omega)$ resonances are obtained. As $\epsilon(\omega)$ is complex-valued, an elaborate model [2] is considered for $\epsilon(\omega)$, as an alternate to using the Kramers-Kronig relationship (which requires the entire spectrum).

For numerous years, a specific Atomic spectroscopy was developed to measure the Casimir-Polder Atom-Surface interaction at distances ~ 100 nm (see refs. in [3]); In the specific case of the excited Cs(7P) atom in front of a sapphire surface, thermally emitting sapphire can resonantly couple in the extreme near-field to an excited Cs(7P_{1/2}) atom which absorbs at 12.15 μm (24.678 THz or 0.102eV), but not to the other fine-structure level Cs(7P_{3/2}), where the equivalent absorption,

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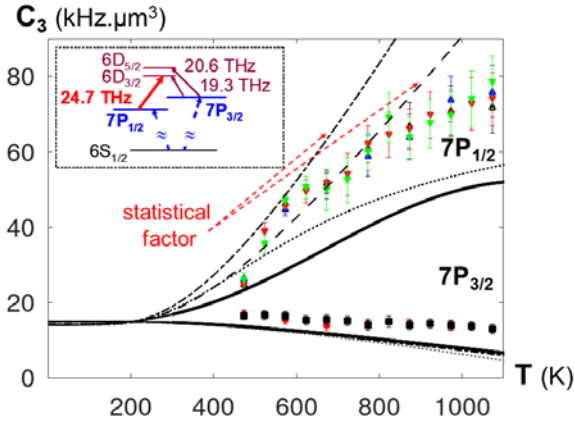


Figure 1: The Atomic Physics measurements clearly show [3] the strong coupling between sapphire surface thermal emission and $Cs(7P_{1/2})$ only. Temperature decreases the sapphire resonance. Nevertheless, the new refined predictions (bold black line) do not improve much the agreement with experimental points (colour). For $Cs(7P_{3/2})$, the imperfect agreement is tentatively attributed to difficulties arising from sapphire birefringence in the far IR range.

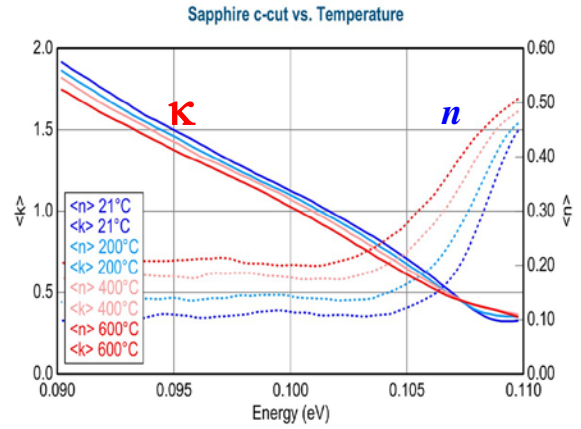


Figure 2: The results of an ellipsometric measurement performed on sapphire at various temperatures. The ellipsometer software directly provides n and κ values. The surface resonance is obtained exactly when $\kappa = 1 + n^2/2$ (i.e. $\kappa \sim 1$), with its amplitude proportional to n^{-1} (n remains nearly flat around the surface resonance). In these preliminary studies, birefringence was neglected despite the oblique incidence of the ellipsometer onto the c-cut window.

at $\sim 15 \mu\text{m}$, is too far away. The strength of the resonant coupling, determined by a $-C_3z^{-3}$ potential (z : the atom-surface distance) is governed by $\Re[S(\omega, T)]$. As shown [3] by fig. 1, the measured $C_3(T)$ has a growth smaller than expected from pure thermal statistics, owing to the broadening of the sapphire surface resonance with temperature. However, the *ad hoc* emissivity measurements on the same sapphire window do not improve much the agreement. Also, a real energy transfer, expected from the sharper resonance for $\Im[S(\omega)]$, has remained unobserved [3]. Owing to the Lorentzian nature of $S(\omega)$ around its resonance [4], we can suspect [3] the effective sapphire surface resonance to be larger and red-shifted, relatively to predictions originating from bulk emissivity.

3. ELLIPSOMETRY AS A DIRECT WAY TO EVALUATE SURFACE RESONANCES

Dielectric permittivity is fine to describe the entire spectrum, but around the surface resonance $S(\omega)$, it is convenient to keep the optical constants of index and absorption, i.e. $\epsilon(\omega) = (n+i\kappa)^2$. Indeed, for a surface resonance $\epsilon(\omega) \sim -1$, corresponds to $\kappa \sim 1$ and $n \ll 1$ [4]. Far IR ellipsometry allows direct measurements of n and κ in the range of thermal emission. Preliminary measurements (fig. 2) evidence the temperature displacement of the sapphire surface resonance. In a further effort, birefringence (for sapphire, but SiC too) will be fully considered. Several materials will be analyzed and expectedly reported at the meeting.

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