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Atom-Surface Interaction Turned into a Diagnostics of Spectrally Sharp Near-Field Thermal Emission by a Surface Polariton – Comparison with Predictions of Far-Field Emissivity and with Ellipsometry

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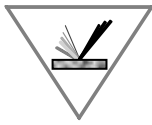
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LASER SPECTROSCOPY AND METROLOGY

IL.B1

ATOM-SURFACE INTERACTION TURNED INTO A DIAGNOSTICS OF SPECTRALLY SHARP NEAR-FIELD THERMAL EMISSION BY A SURFACE POLARITON – COMPARISON WITH PREDICTIONS OF FAR-FIELD EMISSIVITY AND WITH ELLIPSOMETRY

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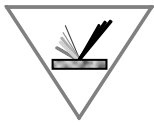
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Thermal emission in the near-field has been a topic of major interest since the turn of the century [1]. It strongly differs from the universal blackbody emission because of the coupling with evanescent modes of the emitting body enhanced for distances $\leq hc/kT$ (i.e. 5-50 μm). Thermal emission becomes 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 novel applications (e.g. thermal diodes, thermal spectral lamp), but the predictions are material-dependent and 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.

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 $S(\omega) = [\varepsilon(\omega) - 1] / [\varepsilon(\omega) + 1]$, where $\varepsilon(\omega)$ is the relative dielectric permittivity of the material at frequency ω . This permittivity exhibits a temperature-dependence $\varepsilon(\omega, T)$. A difficulty is that the resonance for $S(\omega, T)$ appears for $\varepsilon(\omega, T) \sim -1$, in a range far away from any resonance for $\varepsilon(\omega)$, where the material is moreover strongly absorbing – i.e. it is not an "optical window". The relative permittivity $\varepsilon(\omega, T)$ is usually determined with experimental spectra of reflectivity (or equivalently, thermal emissivity) and an elaborate modelling, from which $S(\omega)$ resonances are obtained. As $\varepsilon(\omega)$ is complex-valued, an elaborate model [2] is considered for $\varepsilon(\omega)$, 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 0.102 eV), but not to the other fine-structure level Cs(7P_{3/2}), where the equivalent absorption, at ~ 15 μm , 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 $\Re[S(\omega, T)]$. The measured $C_3(T)$ has actually a growth smaller than expected from pure thermal statistics, owing to the broadening of the sapphire surface resonance with temperature [3]. 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



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unobserved [3]. The Lorentzian nature of $S(\omega)$ around its resonance [4] led us to suspect [3] that the effective sapphire surface resonance could be red-shifted, and with a larger amplitude, relatively to predictions originating from bulk emissivity.

Surface resonances $S(\omega)$ are more conveniently described by optical constants [index and absorption, i.e. $\varepsilon(\omega) = (n+i\kappa)$], as the surface resonance, appearing when $\varepsilon(\omega) \sim -1$, requires $\kappa \sim 1$ and $n \ll 1$ [4]. Direct measurements of n and κ can be obtained by far IR ellipsometry. Our measurements, evidencing the temperature displacement of the sapphire surface resonance, still agree with estimates from emissivity, and include the analysis of sapphire birefringence. We will discuss possible limiting factors in our (near-field) atomic physics methods, and also intrinsic differences between near-field and far-field measurements.

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