X-ray Diffractive Casimir Effect

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Introduction

The Casimir effect [1] is an attractive force between a pair of closely spaced conductors or dielectrics due to a separation-dependent reduction of the electromagnetic vacuum energy density. The same concept also applies to critical fluctuations in spatially restrained condensed matter [2]. A Casimir force has been measured by several groups at micrometer scales (see for example [3]). It would be highly interesting to get data at shorter wavelengths and thus obtain a direct measurement of the electromagnetic vacuum energy density and address the ultraviolet problem of quantum electrodynamics. For x-rays, no normal-incidence mirrors exist, and one has to use crystal back-reflection instead.

The physics is therefore a little different from the Casimir effect at micrometer scales and can be described in terms of dynamical x-ray diffraction: The difference in absorption on the α and β branches of dynamical diffraction leads to a modification of the electromagnetic density of states. Because the affected modes and their photon energies depend on the lattice parameter, there should be a resulting force (i.e., a spatial derivative of an energy) in analogy to the Casimir force. In most cases, it would be indistinguishable from elastic forces in the crystal due to the chemical bonding, *except* if the wavelength of an x-ray absorption edge of an elemental species in the crystal matches the backscattering condition for some set of lattice planes. As one tunes the lattice parameter with temperature, mechanical stress, etc., the number of modes for the absorption edge wavelength available on the low-absorption α branch rises to a peak at exact backscattering and drops sharply when the lattice becomes too closely spaced. The same is of course also true for the high-absorption β branch, but since it is the geometric mean of the corresponding absorption lengths that equals the average absorption length, while the electromagnetic density of states depends on the arithmetic mean, a jump results at the backscattering condition. One would expect a slight anomaly of the lattice parameter due to this jump. A rough order-of-magnitude estimate, comparing the energy of one-half photon at the Te K edge at 31814 eV with the elastic energy stored in the quantization volume yields a relative lattice parameter anomaly of ca. 10^{-5}.

Methods and Materials

The experiments addressed in this report were conducted on a sample of TeO_2 (space group $P4_12_12$, measured unit cell parameters: $a = b = 4.8086$ Å, $c = 7.611$ Å). It was chosen because several x-ray reflections in it match the backscattering condition at the Te K absorption edge with only moderate temperature tuning, due to the relatively short wavelength of the Te K edge. So far, three beam times have been devoted to the x-ray diffractive Casimir effect (Nov. 01 at 7-ID, Dec. 01 at 1-BM, and Feb. 02 at 7-ID). In the first of these, the sample was about 11x20x40 mm^3 in size with the (1 1 0) axis along the normal vector of the small surface. Because the sample had arrived only just before the beam time, it was not possible to construct a strain-free sample mount with good thermal control. Instead, the crystal was glued to a thermoelectric cooler and thermally insulated with polyurethane foam. The lattice parameter of the (8 8 2) reflection was then measured by back-reflecting ($\Theta = 89.95°$) x-rays of 14.795 keV from Si (10 8 2) onto a polished (1 1 0) surface, and thence with $\Theta = 82.57°$ to an Oxford Cyberstar scintillation detector.

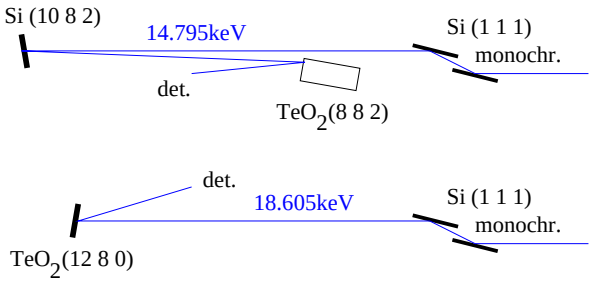

Figure 1: *Double- and single-backscattering geometry.*

In the other two beam times, a slice from the above sample, 1mm thick in the (1 1 0) direction and polished on both faces, was epoxy glued in an upright position on its (1 $\bar{1}$ 0) side to a thermoelectric cooler/heater and placed in a rough vacuum for thermal insulation. The x-rays hit the other end, ca. 15 mm away from the glue under conditions of near backscattering at $\Theta = 88°$ for the (12 8 0) reflection at 18.605 keV. These x-rays are ONLY a tool to measure lattice parameters and are unrelated to the x-ray vacuum fluctuations underlying the Casimir effect.

Results

Figure 2 shows the (8 8 2) peak position over the sample temperature at a cooling rate of 8K in 3 hours. There is a kink in the curve at 292.3K, which could indicate an anomaly in the thermal expansion due to the Casimir effect (but see discussion). In the data

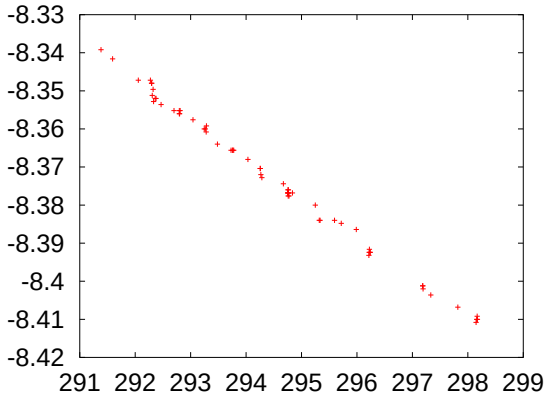

Figure 2: *(8 8 2) peak position in degrees with arbitrary offset over sample temperature (in Kelvin).*

from 1-BM (taken without back reflection from Si), no such kink appears. Instead, that data could contain evidence of another kind. Figure 3 shows a contour plot of the (12 8 0) reflection vs. angle and temperature. The streaks are due to other reflections, going into non-backscattering directions. Two of them are interrupted in places indicated by arrows. This effect is even more pronounced in the data of Feb. 02 (to be shown in the next annual report). It could be due to a change in the triplet phase of dynamical multibeam diffraction, caused by a Casimir-induced change in the structure factors (see discussion).

Discussion

The kink in Fig. 2 could be due to the Casimir effect with the back reflection condition met within 1K by both the (13 20 10) and the (14 10 28) reflections [and all symmetry-equivalent ones such as (20 13 10), or ($\bar{1}3$ 20 10)]. However, due to the way the sample was

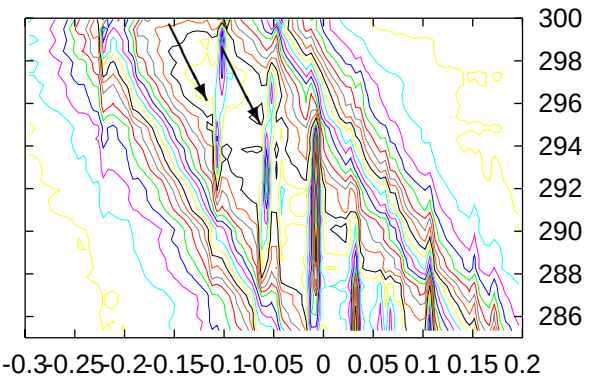

Figure 3: *Contour plot of the (12 8 0) reflection over angle (in degrees) and temperature (in Kelvin). The arrows indicate interruptions in secondary reflections (see text).*

mounted, the quality of the raw data is insufficient to draw a definite conclusion. The data shown are from a single pass of the temperature from 299K to 291K. After reaching 291K, the sample was heated at a fivefold more rapid rate, and the data from that temperature pass (with correspondingly fewer data points) do not show a kink.

In the data from a thin slice of TeO_2, mounted with less strain and better thermal insulation, no such kink is seen, but instead, the triplet phases of a secondary reflection seems to change transiently with the temperature. This could be due to the Casimir effect coupling to static distortions within the unit cell (i.e., soft optical phonons), and thus changing the structure factors relevant for multibeam dynamical diffraction. Detailed modeling of that hypothesis is in progress.

Acknowledgments

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