Optics With Superhydrophobic Surfaces – a New Class of Switches and Sensors

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Abstract: We introduce the use of structured hydrophobic surfaces for optical switches and sensors and demonstrate an ultra sensitive ultrasound sensor based on a superhydrophobic diffraction grating. Superhydrophobic photonic crystals promise devices with tunable stop band.

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We etched micron size rectangular grooves into a silicon wafer and hydrophobized it by vapor deposition of a self-assembled monolayer of an alkylsilane[1]. Upon immersion in water, ambient air is trapped in each groove and a meniscus is pinned along the rim of the groove as sketched in the inset of Fig.1. The result is an optical grating, whose diffraction efficiency depends on the *curvature* of the menisci. First, we determine the curvature of the menisci by measuring the intensity of the diffraction orders as a function of incident angle and solving the inverse diffraction problem by means of Rigorous Coupled Wave Analysis (RCWA)[2]. Fig.1 shows the intensity of the -1^{st} diffraction order. The measured data is compared to data calculated with varying curvature κ of the menisci. The best fit determines the measured curvature. This procedure accurately 'solves' the inverse diffraction problem and reveals the curvature of the menisci. The curvature depends on the pressure difference ΔP accross the interface and is given by the Laplace law $\sigma\kappa = \Delta P$, where σ is the water surface tension. By controlling the water pressure, we are able to bend the menisci inwards. The inset in Fig.1 shows the measured curvature as a function of pressure showing that the curvature follows Laplace's law.

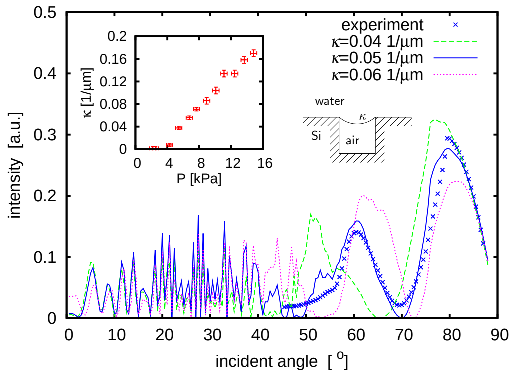

Fig. 1: Intensity of the -1^{st} diffraction order. The best fit of RCWA calculation (lines) to the experimental data (crosses) determines the curvature of the menisci.

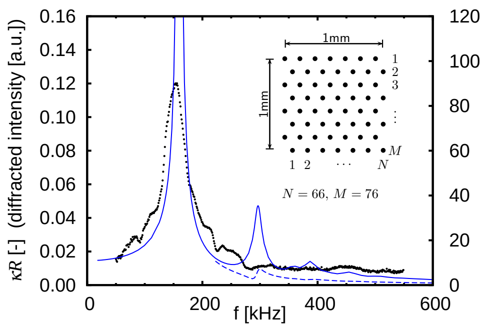

Fig. 2: Ultrasound frequency response of an array of micromenisci. The ordinates denote the non–dimensionalized curvature κR (R hole radius) and the deflection z of the meniscus' apex.

To have full control about the microscopic hydrodynamics, we modify the device to a $1 \times 1\text{mm}^2$ wide array of cylindrical holes as shown in the inset of Fig.2. The diffracted intensity can be understood in the Fraunhofer limit, where it is proportional to the intensity diffracted from a single unit cell[3]. For gracing angles – when total reflection occurs at the menisci – this is approximately a two-beam interference between the wave diffracted from the meniscus and the wave diffracted from the flat silicon surface. Therefore, the diffracted intensity easily reveals nanometer scale deflections of the menisci. In addition, the menisci are very soft 'hydrophone membranes' – their spring constant is extremely small. This makes the device a promising candidate for a next generation ultra sensitive ultrasound sensor. Fig.2 shows the frequency response of such a device. Experimental data is in agreement with unsteady Stokes flow theory taking into account hydrodynamic interaction.

To increase the ultrasound bandwidth, the size of the menisci has to be reduced. At the same time a device based on integrated optics is favored for sensor applications. Therefore our road goes now towards hydrophobic photonic crystals and to observe (in reflection or in transmission) the shift of the stop band as the menisci oscillate inwards and outwards. Since the curvature of the menisci is controllable by the static pressure, this is a new route to tunable stop bands in photonic crystals.

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