EPJ Web of Conferences **190**, 02008 (2018) https://doi.org/10.1051/epjconf/201819002008
HBSM-2018

Investigation of evaporation of sessile droplets using luminescent nano-probes and other applications of NV centers in diamond

Taras Plakhotnik* and *Haroon* Aman

School of Mathematics and Physics, The University of Queensland, St Lucia, QLD 4072, Australia

Abstract. The paper describes application of diamond nano crystals to research on dynamic processes in small (less than 1 mm across) evaporating droplets deposited on a solid substrate. Such droplets are used as a model system for testing proposed bio applications of nitrogen-vacancy centers in diamond. We demonstrate that a high spatial resolution of our methods reveals unexpected features of the evaporation and fluid mechanics in such droplets.

Research on nitrogen-vacancy centers in diamond (NV-centers) has gained its momentum about 30 years ago and since then the field has developed in several directions. One direction of research mainly exploits very stable luminescence of these centers, which may in bulk crystal environment can escape photo bleaching during several weeks of continues photo excitation. If such centers are embedded in very small (tens of nanometers or less) crystals, these crystals can be used as luminescent labels in bio imaging applications (such as tracking and targeted visualization) where they successfully compete with conventionally used organic dyes and quantum dots. However the necessity to use nano-crystals has a number of undesired consequences of practical importance such as significantly reduced luminescence rate [1].

In this report we demonstrate applications of nano-diamonds for investigation of fluid dynamics in small evaporating droplets deposited on a solid surface. This system (where physics is not yet completely described with quantitative models) is interesting by itself but also provides a simple playground for developing and testing concepts employed in corresponding intracellular applications.

A very popular physical model for the evaporating droplet has been suggested 20 years ago in a seminal paper [2] and it predicts that the velocity of the fluid in the evaporating droplet deposited on a solid substrate increases towards the rim of the droplet. This velocity is proportional to $x^{-\lambda}$, where x is the distance to the rim while the value of $\lambda = (\pi-2\theta)/(2\pi-2\theta)$ depends on θ, the contact angle between the droplet and the substrate.

The experimental results obtained by tracing a 35-nm diamond with about 20-nm accuracy are shown in Fig. 1. Contrary to the theoretical predictions, the data do not show acceleration towards the rim and careful analysis of diffusion points to a decrease of velocity of liquid within less than 2-μm distance from the rim.

* Corresponding author: taras@physics.uq.edu.au

A very interesting prospect for NV centers is their sensitivity to various external parameters such as magnetic and electrical field and temperature [3]. Magnetic field sensors based on NV-centers exploit a not zero spin of the electronic ground state of these defects in diamond lattice and the dependence of the luminesce intensity on the spin state (the value of its projection on the center axis). Temperature measurements can either use the sensitivity of the ODMR frequency to the crystal temperature (the resonance shifts with a gradient of 75 kHz/K [4]) or the thermal sensitivity of the zero-phonon line (ZPL) in the luminescence spectra (ZPL of NV-centers is clearly visible even at room temperature) [5].

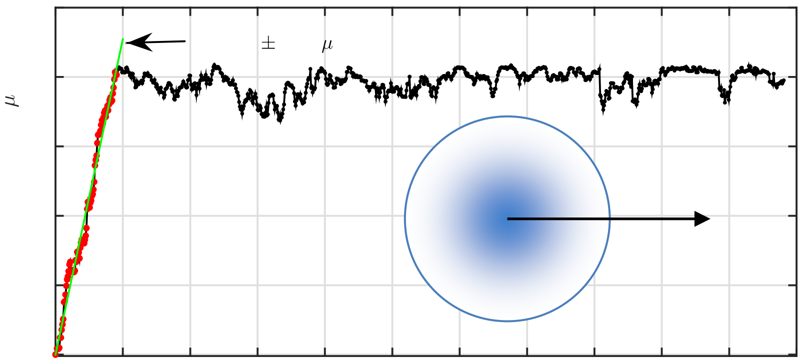

Fig. 1. The *x*-position vs. time for a nano-diamond when it approaches the rim of a droplet. The initial position on the *x*-axis and the time are set to zero at the start of tracing. The position of the rim corresponds to the displacement $x \approx 21$ µm. For ≈ 2 s the diamond drifts towards the rim with a constant velocity of about 11.4 µm/s and then its movement is described near the rim as constrained diffusion in a steady liquid flow. The inset shows the droplet and the direction of the *x*-axis.

Temperature measurements inside biological cells have raised recently a hot debate among physicist, biophysicists and biologists. The discussion is focused on the temperature rise in single cells under physiological conditions. Simple physical arguments suggest that a cell generate very small temperature gradients (even on a 100-nm scale the estimated temperature difference is less than 1 mK). But some experimental results show a local temperature rise on the order of 1 K. The contradiction has been even named as “The 10^5 gap” paradox [6]. Most of the measurements in this area are done using thermo sensitive dyes and their reliability is questioned due to their sensitivity to other factors. The solution of this contradiction requires new methods for sensitive and ultra local temperature measurements. Because most of the reported measurements of temperature in evaporating droplets also lack reliability, we propose to investigate evaporative cooling in micro-droplets using NV-centers in nano-crystals as thermometers. Such a model system is a reasonable proxy to the complex intracellular measurements.

References

1. T. Plakhotnik, H. Aman, Diamond Rel. Mater. **82**, 87 (2018)
2. R. D. Deegan et al, Nature **389,** 827 (1997)
3. T. Plakhotnik, Curr. Opin. Solid State Mat. Sci. **21**, 25 (2017)
4. V. M. Acosta et al. Phys. Rev. Lett. **104**, 070801 (2010)
5. T. Plakhotnik, H. Aman, H.-C. Chang, Nanotechnology **26**, 245501 (2015)
6. M. Suzuki et al., Nature Methods **12,** 802 (2015)