Trapping of ions, charged clusters, and microparticles under a free surface of superfluid helium and a mesoscopic network formation

P. Moroshkin[1], P. Leiderer[1,2], K. Kono[1]

[1]*RIKEN, Center for Emergent Matter Science, Wako, Japan*
[2]*University of Konstanz, Konstanz, Germany*

He^+ ions (snowballs) and free electrons (electron bubbles) can be trapped under a free surface of superfluid He by applying a suitable static electric field. We develop a new experimental technique for trapping positive ions of various metals under free He surface for their subsequent laser-spectroscopic studies. Our aim is to produce a two-dimensional pool of spin-polarized Ba^+ ions and to investigate their depolarization due to the interaction with the surface elementary excitations [1].

Ions, electrically charged metal clusters and microparticles are produced by laser ablation in superfluid ^4He and move upwards in a vertical static electric field. They become trapped under the free surface of superfluid He and are observed via light scattering (see Fig.1a). In a vertical electric field of 0.5 – 2.0 kV/cm, the charged liquid surface experiences various static and dynamic perturbations that are visualized using a fast video camera. In particular, we observe lifting of He surface, formation of static hillocks (see Fig.1a) and running waves. Under the electric field exceeding some threshold, the charges escape from the surface by forming jets or geysers of liquid He shooting upwards on a time scale of 1 ms and having a diameter of ≈0.05 mm. Similar behaviour is observed with positive and negative charges, under the electric field directed up and down, respectively.

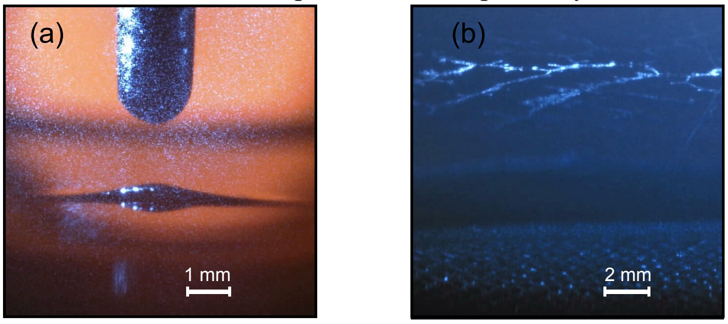

Fig1. (a) Charged liquid He surface in electric field; (b) metallic filaments trapped at liquid He surface

Very large number of trapped particles is generated also with the ablation target positioned in He gas above the liquid He surface and with the electric field directed downwards. At the surface, the trapped particles coalesce into larger structures: filaments with very large aspect ratios and mesoscopic networks (see Fig.1b). Since all the particles reaching the surface posses positive electrical charge, they must experience repulsive Coulomb forces that would prevent their coalescence. One possibility is that some positively charged particles first penetrate into the liquid and reach the bottom (negative) electrode. There they exchange their charge to negative and are driven back to the liquid surface by the electric field. Such particles could be stabilized under the liquid surface due to the surface tension and act as seeds for the coalescence of further positively charged particles arriving from above.

Formation of long filaments (nanowires) has been demonstrated earlier in several experiments involving laser ablation of metals in bulk superfluid He (see, *e.g.*, [2]) and doped He nanodroplets [3]. It was suggested that the filaments are formed via the coalescence of nanoparticles and/or single atoms trapped at the cores of quantized vortices. Considering the highly branched structure of the networks observed in the present experiment and their tendency to grow at a free surface rather than in the bulk liquid, we suggest that the formation process is dominated by the electrostatic interaction between charged micro- and nanoparticles and by their interaction with the He surface, rather than by trapping at quantized vortices.

1. Batulin *et al*., J. Low Temp. Phys., **175**, 63 (2014)
2. Moroshkin *et al*., Europhys. Lett., **90**, 34002 (2010)
3. Gomez *et al*., Phys. Rev. Lett., **108**, 155302 (2012)