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► **To cite this version:**

Julien Salort, Alessandro Monfardini, Philippe-Emmanuel Roche. Micro-Cantilever Anemometer for Cryogenic Helium. *Journal of Physics: Conference Series*, 2011, 318, pp.092030. 10.1088/1742-6596/318/9/092030 . hal-00640527

HAL Id: hal-00640527

<https://hal.science/hal-00640527>

Submitted on 13 Nov 2011

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Micro-Cantilever Anemometer for Cryogenic Helium

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Abstract. We present a new anemometer for liquid helium, based on a micro-cantilever. Our aim was to design a probe significantly smaller than one millimeter and that can be used both above and below the superfluid transition at $T_\lambda = 2.17$ K. This sensor, including its bearing arms, is fully micro-machined using “Deep Reactive Ion Etching” techniques on a silicon wafer. This lets us choose the geometry of the arms to make them as little invasive as possible. The deflection of the cantilever, which reflects the local fluid velocity, is probed using a niobium superconducting LC resonator, with a critical temperature $T_c \approx 9$ K.

1. Motivations for a new anemometer in superfluid helium

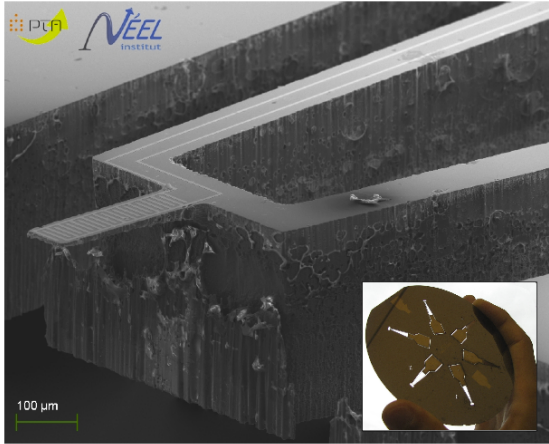
Below 2.17 K, liquid helium undergoes a phase transition: the new phase is called He II. The hydrodynamics of this phase can be described by the so-called two-fluid model, ie. as a superposition of a normal component which behaves like a classical Navier-Stokes fluid (finite viscosity) and a superfluid one with zero-viscosity and quantized vorticity. When the fluid velocity is sufficiently high, the system becomes “turbulent”. The understanding of this turbulence, often called “quantum turbulence”, suffers from the lack experimental data. Indeed, until now, there have been only two types of local measurements in turbulent superfluid flows: (i) velocity measurements using millimeter-sized stagnation pressure probes (Maurer & Tabeling, 1998; Salort *et al.*, 2010) and (ii) quantum vortex lines density measurements using micro-machined “second sound tweezers” (Roche *et al.*, 2007). The former probes have shown that the superfluid can undergo a Kolmogorov cascade at large scale but cannot resolve the smaller scales of the flow because of their size. The latter has brought the first non-classical local statistics and led to a new statistical model for vortex spectra in superfluid turbulence (Roche & Barenghi, 2008) but can only work in the superfluid phase and thus cannot be used to make direct comparison of quantum turbulence and classical turbulence.

To go further into the physics of quantum turbulence, it is therefore necessary to have smaller probes that can work in both above and below the superfluid transition. One possibility is to adapt the cantilever-based techniques that are fruitful at room temperature (Barth *et al.*, 2005). The main goal of this talk is to describe a working prototype of such a probe.

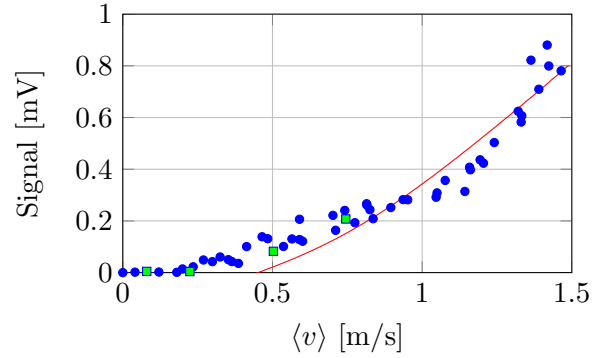
2. Design of a micro-cantilever anemometer in cryogenic helium

We have developed a micro-machining process to build a $300 \mu\text{m} \times 50 \mu\text{m} \times 1 \mu\text{m}$ silicon cantilever shown on the SEM pictures (a). This structure is etched directly in the bulk of a silicon wafer (see inset of figure a). The cantilever is therefore made of mono-crystalline silicon and thus does not hold residual stresses. This cantilever is placed in a liquid helium flow, which entails its

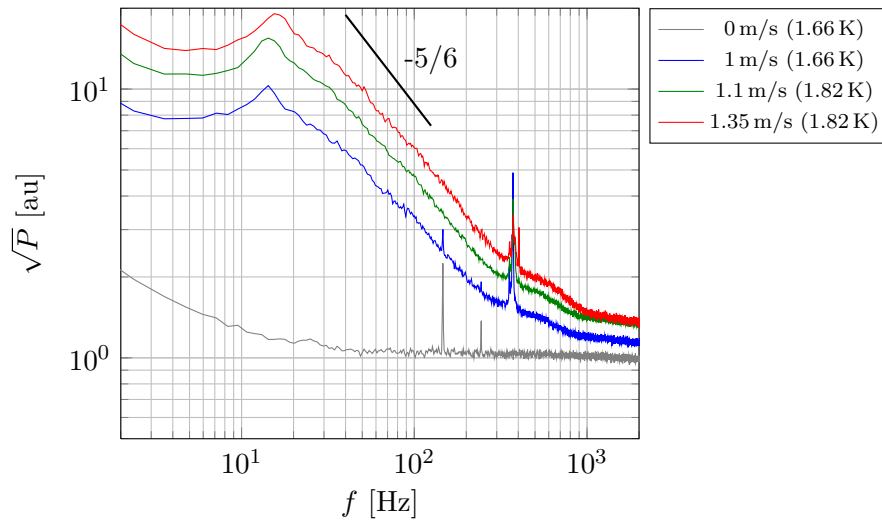
deflection, proportional to the square of the local flow velocity. The detection of this deflection is based on a niobium superconducting radio-frequency LC resonator. Its frequency depends on the deformation of the inter-digital capacitor sputtered on the cantilever itself.



(a) Overall view of a cantilever



(b) Calibrations of the cantilever signal versus the flow mean velocity using slow sweeps (\bullet), mean value of time series recording (\blacksquare) or a AC calibration around 1 m/s (---).



(c) Velocity power spectrum measured with the first cryogenic cantilever anemometer prototype.

As expected, the measured signal is proportional to the square of the mean velocity (see figure b) and the sensibility is the roughly the same for AC or DC velocity signal. The first velocity spectrum measurement is shown on figure c. The scaling is fairly compatible with Kolmogorov $\sqrt{k^{-5/3}}$. This measurement was realized in the far-wake of a centered 11 mm brass disc in the wind tunnel described in (Roche *et al.*, 2007). The noise floor at 1 kHz is close to what we get with the best anemometers known to work in superfluid helium.

The sensibility of this prototype was limited by the quality factor of the superconducting resonator. There is good chance that this can be much improved in the future. Therefore, although some further work is needed, we believe that this technology may supersede stagnation pressure probes in the future because it has some definite advantages: (i) it is roughly immune to most acoustic noises whereas stagnation pressure probes are basically microphones and (ii) the micro-machining process should allow much smaller probe size.

3. Acknowledgments

This work was performed with the help of “Plateforme Technologie Amont” (PTA) in Grenoble and with the financial support of the ANR (grants “SHREK” ANR-09-BLAN-0094 and “MKIDS” ANR-09-JCJC-0021-01). We are grateful to T. Haccart, S. Litaudon, F. Gustavo, C. Lemonias and J.-L. Thomassin for their expertise in the clean room. We thank G. Garde for his availability and skills on the cryogenic apparatus.

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