Probing Vortex Density Fluctuations in Superfluid Turbulence

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1 Introduction

The flow dynamics of a superfluid can be described by a viscousless tangle of quantized vortex lines [1, 2, 3, 4]. In spite of these unusual mechanical properties, strong similarities have been reported between superfluid (or "quantum") turbulence and its Navier-Stockes counterpart. Most of them were detected by macroscopic sensors probing the largest scales (integral length) of the flow. At smaller scales, the zero-viscosity and quantization is expected to ruin this similarity between the two turbulences but probing the inertial range is already an experimental challenge [5]. In a keystone experiment, Maurer and Tabeling measured local fluctuations in a bulk flow of helium with and without superfluid[6]. In both case, they found a Kolmogorov-like spectrum for velocity in the inertial range, which has been confirmed since by numerical simulations [7, 8, 9].

Recently, we micro-machined and operated a local probe of the vortex line density fluctuations (projected on a plane). It provides a second direct experimental characterization of the inertial range of superfluid turbulence. The flow, the operation of this probe and the first physical results are presented in another paper[10]. On figure 1 (left), we illustrate these results with power spectra of the vortex line density. In the present paper, we present further details on micro-machining of the probe. To our knowledge, this is the first fully micro-machined sensor used in a cryogenic turbulence experiment.

2 Flow and Probe

The flow

The flow is confined in a cryostat and continuously powered by a centrifugal pump (see figure 1). Turbulence is probed in a 23 mm-diameter pipe, located upstream from the pump. Velocity can span the range $0.25 - 1.3\, m/s$. The

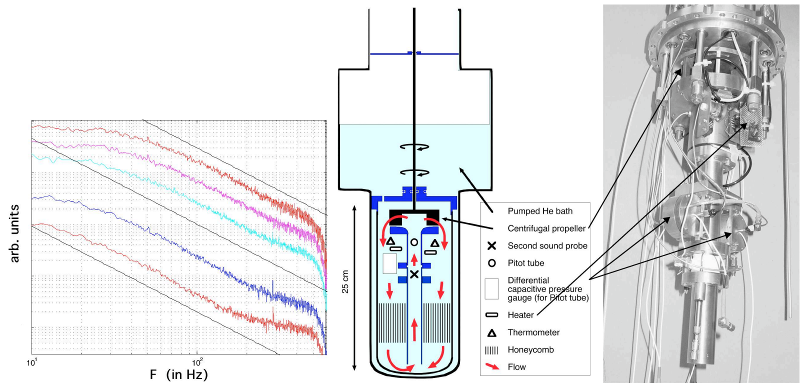

Fig. 1. (Left) Power spectrum of the projected vortex line density for a mean velocities from 0.25 (bottom curve) up to 0.78 m/s (top curve). Saturations at high frequencies result from the noise floor and filtering. Solid lines are -5/3 power laws. (Center and Right) The closed loop of He.

measurements are performed in ^{4}He near $1.6\,K$. In such conditions, 84% of helium is superfluid, the rest being a normal (viscous) fluid superimposed to the superfluid. More details are presented in [10].

The probe's micro-machining

The principle of operation of the sensor is presented in [10]. In short, it consists in an open second-sound resonator inserted across the flow. Second sound (thermal waves) is known to be attenuated by the vortex lines which are polarized in the plane of propagation[1]. Thus, a time-resolved measurement of the standing wave amplitude provides a direct measurement of the total length of the (projected) vortices within the fluid element advected through the resonator. This signal is somehow analog to an enstrophy defined using a projected vorticity.

Both mirrors of the cavity are $15\,\mu m$ thick silicon beams separated by a $250\,\mu m$ gap. The length and width of both beams is $1.5\,mm$ x $1\,mm$ and they are facing each other with a lateral positioning within a few tenths of mm typically. A granular Al film is deposited over a $0.8\,mm$ square area at the tip of one beam. This film is used as transition edge superconducting thermometer. Facing this thermometer, a chromium heating film is deposited on the tip of the other beam. Between both beams, a third silicon spacer sets the gap of the cavity. On both sides of it, contact pads provide electrical connections of both beams to the electronic circuit.

The micro-machining process is given in figure 2. SOI wafers (4 inches diameter) have been used with the following typical thicknesses of the 3 layers : $15\mu m$, $0.5\mu m$ and $500\ \mu m$. Figure 3 (left and center) shows the wafer with

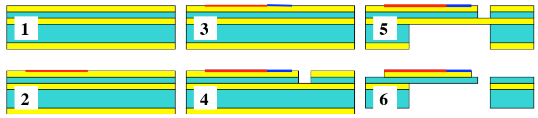

Fig. 2. Steps of the micro-machining process of one beam (the other beam is machined following a similar procedure). 1-Electrical isolation (thermal oxidation, 400 nm), 2-contact pads (Cr 150 nm, Au 500 nm), 3-Heater (Cr, 500 nm), 4-DRIE front side (15 μm), 5-DRIE back side (500 μm), 6-oxide, cleaning...

beams of various sizes. The picture on figure 3 shows the resonator after assembly.

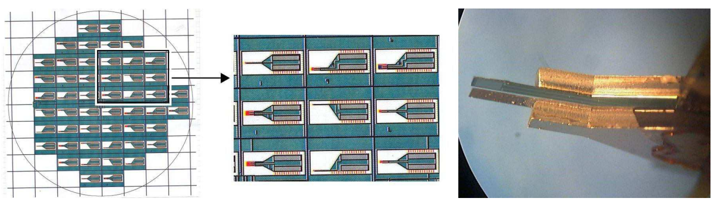

Fig. 3. (Left) Schematics of a region of the wafer, at the end of the micro-machining process. (Right) Picture of the tip of the probe after assembly.

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