# Sub-millimeter Size Sensors for Measurements in Cryogenic Turbulence

Yihui Zhou[*], Vadim F. Mitin[+], Shu-chen Liu[*], Isaac Luria[*], Mario Padron[*], Ridvan Adjimambetov[*], and Gary G. Ihas[*]

[*] *Department of Physics, University of Florida, Gainesville, FL 32611-8440, USA*
[+] *V. Lashkarev Institute of Semiconductor Physics, NASU, Kiev, Ukraine*

**Abstract.** Classical turbulence research is advancing by utilizing MEMS temperature and pressure fluctuation sensor technology. Turbulence research at cryogenic temperatures has many advantages over the classical approach, such as extreme stability of control parameters and very high Reynolds numbers in small apparatus. However, changes in material properties from room temperature to 1 K (and below) make most sensors unusable at low temperature. A new type of thermistor, incorporating a Ge-film deposited on a GaAs substrate, has been designed. It provides high sensitivity in the range of 20 mK to 5 K. In this paper, the design and characteristics of these sensors is discussed, and experimental data from three thermistors is presented. Progress on a miniature pressure transducer is also described

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## INTRODUCTION

Turbulence in a superfluid, such as liquid helium, has been studied for many years. An understanding of this form of turbulence is crucial for us to apply superfluid helium as a coolant for superconducting magnets, RF cavities, and other applications.

In classical fluids, the energy transfer in the inertial region of homogeneous isotropic turbulence can be described by the Kolmogorov spectrum before it is dissipated by viscosity. So far, almost all superfluid turbulence experiments have been carried out at temperatures above 1 K, where there is a significant fraction of normal fluid component. For pure superfluid turbulence at much lower temperature, various decay mechanisms have been suggested and all depend on vortex reconnections. One considers energy flow from scales of order *l* (vortex line spacing) into the Kelvin waves on the vorticity. A Kelvin wave can radiate phonons, and the radiation is significant at high frequencies [1]. It has been proposed that there be a kind of Kelvin-wave cascade analogous in some respects to the classical Kolmogorov cascade.

One of the purposes of our experiment is to search for the possible dissipative processes operating at very low temperature. To produce isotropic homogeneous turbulence, a grid is towed through a channel of superfluid helium. A calorimetric technique is used to monitor the decay of turbulence. At low temperature the decay of a random vortex tangle should cause a measurable rise of temperature, proportional to vortex line density. Calorimetry, in principle, should be able to provide evidence both for the existence of a Kolmogorov spectrum on large length scales and for a Kelvin wave cascade on small length scales. This calorimetric measurement method is plausible because sub-millimeter size resistance thermistors can be made to operate over the temperature range 0.02 to 0.10 K. The observation of pressure fluctuations is also useful because it is related to the existence of a Kolmogorov energy spectrum. Very small pressure transducers are required to study the turbulence on a small scale. In this paper, preliminary experimental results and calibrations on such thermistors and attempts made to develop miniature pressure transducers will be presented.

## THERMISTOR AND PRESSURE TRANSDUCER DESIGN

The decay of the turbulence must be measured over five orders of magnitude resolving 1 ms. The temperature change is expected to be of order 50 mK. Hence, the thermistors must have these characteristics:

- Operating temperature: 10 – 100 mK.
- Sensitivity: $\delta T \sim 10^{-4}$ mK.
- Short response time: ~ 1 ms.

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We have developed Ge/GaAs thermistors [2]. The thermosensitive films are prepared by evaporating Ge in vacuum onto a GaAs substrate. By adjusting the processing procedure and parameters of the Ge deposition, the low temperature properties of the thermosensitive film can be made to meet the necessary properties. The thermosensitive element is square 300 μm × 300 μm and 300 μm in thickness. Electrical contacts to the film are made of thin AuGe and Au deposition. Gold wires (50 μm diameter) are thermo-compressed or pulse micro-welded to a deposited metal layer. An Au layer can be grown to provide more reliable microwelding. In order to obtain a sub-millimeter size, there is no packaging to provide mechanical support or protection. Hence the thermistors are delicate.

To make the piezo-resistive pressure transducer [3], a silicon diaphragm is first formed by bulk micromachining. The piezo-resistors are then deposited on or implanted into the diaphragm along its edge. To compensate temperature sensitivity, four resistors are fabricated sitting at each side of the diaphragm and connected as a Wheatstone bridge. All resistors are orientated in the same direction. This kind of arrangement can maximize the sensitivity of the sensor and eliminate the temperature effect as a common mode. The piezoresistive pressure transducer has been preliminarily tested in a Porta-Pot [4] dipped in a liquid helium dewar. Remarkably, the sensitivity (10 Pascal) of the device was roughly constant until the resistances making up the bridge became too large to measure as the temperature was lowered below 40 K. Currently, a new version designed to work at lower temperature is being built.

## THERMISTOR TEST RESULTS

The thermistors were tested and calibrated in liquid and gaseous helium in a copper cell attached to a dilution refrigerator. The cell body was sealed with an indium O-ring. To increase the contact area between the cell body and liquid helium, one layer of sintered silver powder is pressed against the container bottom. The thermistors were suspended from the inside top of the cell by their leads mounted to a circuit board. An ac resistance bridge operating at 10 kHz measured their resistance as a function of temperature. A 100 Ω heater was mounted near the thermistors in the cell. A ruthenium oxide thermometer [5], mounted in the cell cap, served as a calibration reference.

Self heating was observed at about 0.003 nW in the helium vapor and 0.1 nW in liquid. Temporal response was faster than we could measure (0.1 s). A second-sound cell to measure time response is being built.

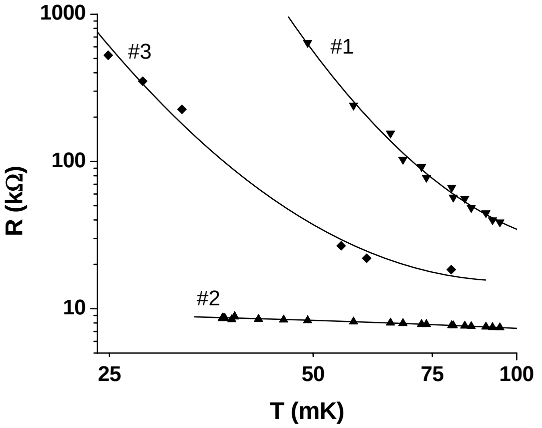

**FIGURE 1.** Calibration for three thermistors against a calibrated ruthenium-oxide thermometer. The gap in data for #3 was caused by a malfunction in the data acquisition system. Room temperature R= 100 Ω for all three sensors.

Three thermistors have been calibrated against a ruthenium oxide thermometer (Fig. 1) [5]. Thermistor #1 is approaching infinity below 40 mK. Thermistor #2 has a resistance of 7 kΩ at 100 mK and changes very little on further cooling. Thermistor #3 seems a good candidate. Its resistance is 20 kΩ at 100 mK and 800 kΩ at 25 mK. By intelligently varying conditions during fabrication, the sensitivity at low temperature has been adjusted to produce a thermistor appropriate for the experiment.

## CONCLUSIONS

Thermal calorimeter and pressure transducer methods have been chosen to study turbulence at very low temperature. They are designed to detect evidence for the existence of a Kolmogorov spectrum on large length scales and for a Kelvin wave cascade on small length scales. Immersed in a test cell filled with liquid helium, bare Ge film thermistors were calibrated down to 25 mK. The results show the Ge film thermistor is useful for calorimetry and the miniature pressure transducers, with higher doped resistors, will work for the study of turbulent superfluid flow.

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