# Millikelvin heater using a light emitting diode and fibre optics

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A method is reported for using light emitting diodes (LEDs) with fibre optics as a source of heating at ultra-low temperatures. The LEDs are mounted on the 4 K flange within the vacuum jacket of a dilution refrigerator and the light is then directed to the millikelvin stage through optical fibres. The cladded fibres have an outer diameter of 125 $\mu$m, with negligible heat capacity and thermal conductivity. Techniques for coupling fibres to LEDs, heat sinking fibres and making a superfluid helium leak-tight fibre-to-copper container seal have been developed. The power output (of the order of nanowatts) is determined as a function of diode drive current.

**Keywords: optical fibres; LEDs; thermal conductivity**

Studies of solid $^3$He at 1 mK have prompted the development of a novel means of depositing heat into an experimental cell as small as 1 mm$^3$. After considering the inadequacies of conventional heating techniques, a method incorporating fibre optics was pursued. In this method, light is produced by a light emitting diode (LED) and then directed to the area of interest through an optical fibre. Such a design has the advantage that the heater need not be thermally anchored to the experiment, since the light can be shone directly on to the sample. Gutsmiedl *et al.*[1] in a preprint have reported using fibre optics in such a manner for heating small high $T_c$ superconductors.

The apparatus used for measuring the LED characteristics and the heat produced by the optical fibre will be described, including techniques for connecting optical fibres to each other, LEDs and cells containing liquid helium. The results of the measurements of the LED characteristics and heat production will be given. Finally, the results will be discussed.

In order to quantify the amount of heat that the LEDs can transmit through the fibre and deposit in a sample, three diodes were mounted on the 4 K flange of a dilution refrigerator. Their placement within the vacuum jacket establishes 4 K as the highest temperature experienced by the fibres when the diodes are off. Two of the LEDs (LED1 and LED2) were thermally anchored to the 4 K flange while the third (LED3) was mounted to the flange through an insulating Vespel spacer (DuPont Company, Wilmington, Delaware, USA). This was done to study the effect of diode self-heating on the power output for a given drive current. To prevent any heat being conducted along the fibre to which the LED was coupled, the fibre was heat sunk to each temperature stage between the diode and the experimental cell, as shown in *Figure 1*. The heat sink was simply several turns of copper wire wrapped around the fibre coated with vacuum grease (Dow Corning Corporation, Midland, Michigan, USA).

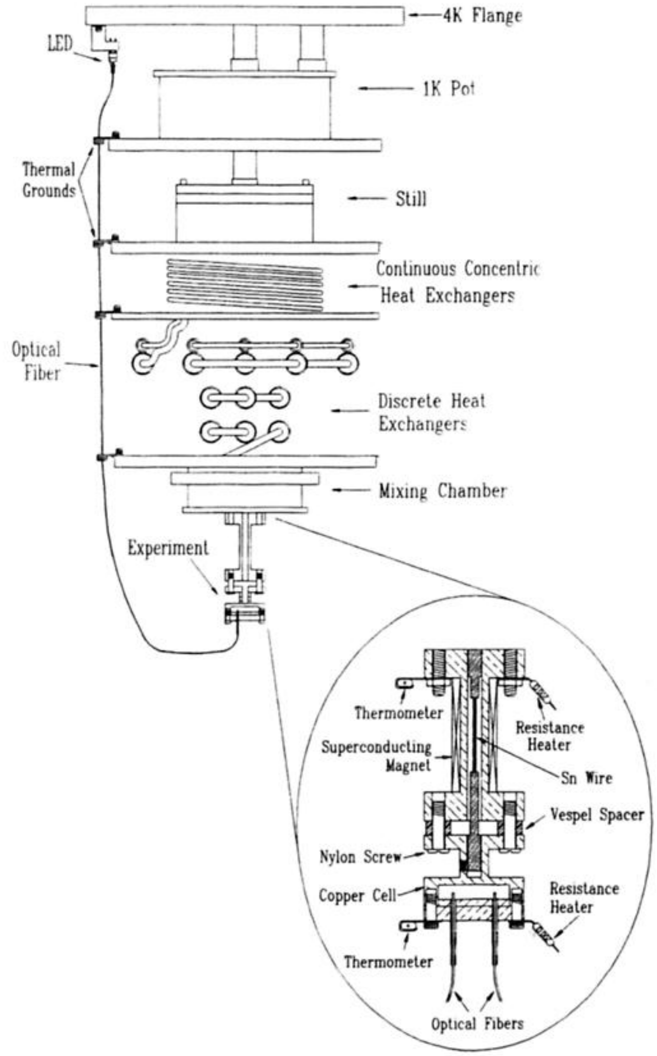


**Figure 1** Diagram of dilution refrigerator showing placement of the LED fibre (only one shown) and experimental cell, as well as an enlarged diagram of the copper chamber, tin wire and superconducting magnet (insulating supports for the dilution refrigerator not shown)

The experimental cell (see *Figure 1*), into which the fibres were then mounted, was constructed of copper. This copper chamber was in turn thermally linked to the mixing chamber of the cryostat through a 99.9% pure tin (Sn) wire. The wire was placed within the bore of a superconducting solenoid magnet (the field lines were parallel to the wire) capable of producing sufficiently high fields to drive the tin normal. Since the thermal conductivity is dependent on the state of the tin, being less when the wire is superconducting, adjusting the magnetic field on the tin also affects its conductivity.

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The tin wire then acts as a variable thermal link, as a function of the applied magnetic field. The magnetic field can be adjusted as the heat load to the cell varies, so that the cell temperature remains constant. A calibration of the conductivity of the tin link *versus* the magnetic field then allows one to determine the heat produced by the fibre. In the measurements presented here, it was found more convenient to hold the magnetic field fixed, producing a weak thermal link, and measure the change in the cell temperature as heat was applied through the optical fibre.

Thermometers[2] were placed both at the refrigerator side and the cell side of the thermal link, allowing the temperature difference to be measured. The conductivity of the thermal link for a given magnetic field strength was calibrated by supplying known amounts of heat to the cell and noting the temperatures. The heat was generated by a 200 Ω resistor attached to the copper chamber and connected with superconducting wires. This yielded a linear relationship for the power input *versus* the temperature difference across the tin wire for a given magnetic field. The typical conductance was of the order of 1 nW $mK^{-1}$.

Once the tin wire had been calibrated, the heating from the fibre optics could be quantified. The LEDs used in the experiment were General Instrument MV50 (General Instrument, Palo Alto, California, USA) and the fibres were Polymicro Technologies FVP 100/110/125 (Polymicro Technologies, Phoenix, Arizona, USA). The fibres, which had a diameter of 125 μm, were 50 cm in length, running from the 4 K flange down to the copper chamber. The connections between the fibre and LED and between the fibre and copper were easily made as described below. The heat entering the cell was determined by driving the LED with a continuous current and noting the temperature difference across the tin wire. This was compared to the calibration to determine the power transmitted to the cell through the optical fibre. This was done for several drive currents; the results obtained at 30 mK are shown in *Figure 2*. The data taken at 20 and 45 mK were similar. To ensure that the effects were not produced by conduction through the fibre, the LEDs were heated externally using resistance wire heaters. No change in temperature was ever observed at the cell in this manner.

As indicated, a suitable means of coupling an optical fibre to an LED and making a helium leak-tight fibre-to-copper seal has been developed. It was found that the simplest method for coupling the fibre to the LED was to use a stainless steel or cupronickel capillary tube whose inner bore is slightly larger than the diameter of the fibre. The procedure is as follows. A hole is drilled into the plastic casing of the diode to facilitate the capillary tube. Care is taken when drilling the hole so that it is properly aligned above the semiconductor chip. Then the capillary is fastened to the diode using an opaque epoxy (Stycast 2850FT, Emerson and Cuming, Canton, Massachusetts, USA), preventing visible radiation of the LED from shining on the rest of the refrigerator. Finally, the optical fibre is inserted into the capillary and held using a varnish from General Electric (GE) (General Electric Corporation, Schenectady, New York, USA). Although GE varnish forms a good bond between the fibre and the diode, it can be removed

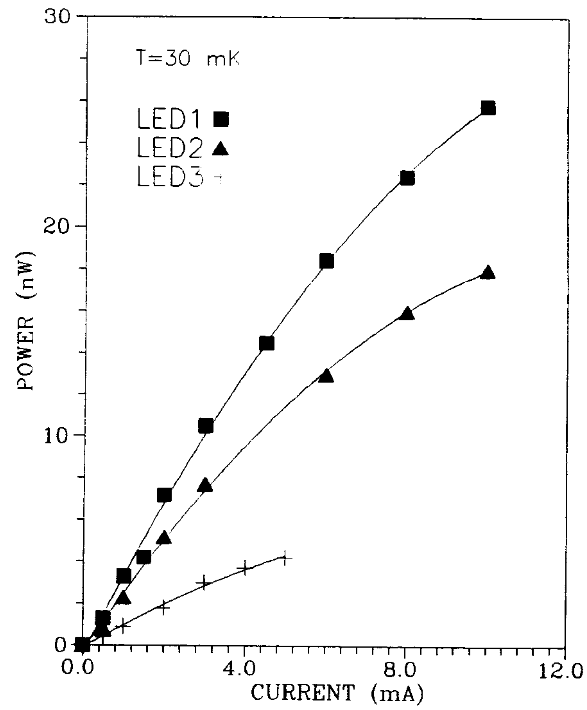


**Figure 2** Power absorbed in liquid $^4$He *versus* diode drive current for the three LEDs and their accompanying fibres for the cell at 30 mK. The lines are the following fits to the data (*P* in nW, *I* in mA): LED1, $P = -(0.13\ \text{nW mA}^{-2})\ I^2 + (3.9\ \text{nW mA}^{-1}) I - 0.44$ nW; LED2, $P = -(0.11\ \text{nW mA}^{-2})\ I^2 + (2.9\ \text{nW mA}^{-1})\ I - 0.27$ nW; LED3, $P = -(0.05\ \text{nW mA}^{-2}) I^2 + (1.1\ \text{nW mA}^{-1})\ I - 0.11$ nW

without much difficulty using a solvent of equal parts of toluene and methyl alcohol.

Capillary tubing can also be used for making a superfluid helium leak-tight seal for passing a fibre through a metal surface. Testing was done using copper but this should not imply that the technique is limited to copper. Again a capillary tube is chosen which had an inner bore slightly larger than the diameter of the fibre. The capillary is passed through a hole drilled through the copper and held in place with silver solder. The fibre is then passed through the capillary and affixed using the 2850FT epoxy.

Some observations can be made concerning the power *versus* current relationships obtained (see *Figure 2*). First it will be noted that the power output from LED3 is considerably less than that of LED1 and LED2. LED3, on the other hand, was mounted differently to LED1 and LED2. Because it was thermally isolated, one expects it to produce less heating in the cell since the efficiency of an LED decreases as its temperature is increased[3]. Earlier tests[4] in the laboratory showed that a drive current of 5 mA should result in roughly 20 mW being dissipated by the diode, which will significantly raise the temperature of the isolated device. The power from LED2 is slightly less than that from LED1. There were no intentional differences in the way that LED1 and LED2 were mounted. In fact, they were specially chosen from a group of LEDs pretested in liquid helium because their $I-V$ plots were so similar. The difference is most likely due to coupling losses. Attenuation at a diode to fibre junction can be as large as 20 dB[5] and the end finish also plays a large role (here the fibres were simply razor-cut).

Inspection of *Figure 2* also reveals that the power increases linearly for low currents and then rises less steeply. The deviation from a straight line is also believed to be due to self-heating. All of the fits shown are second degree polynomials in the current, $I$, with a small, negative coefficient for the quadratic term. So for small drive currents the power increases linearly. Then, as the current is increased, the effects of self-heating become more noticeable and the diode efficiency begins to decrease as the device temperature rises.

Since not all diodes work at helium temperatures, it is convenient to determine if an LED is suitable for low temperature usage by simply inserting it into a liquid helium transport dewar. If the diode is coupled to an optical fibre which is routed outside the dewar, then it can be directly tested by observing the light. Although this method shows without question whether the diode functions or not, one would like to have another means of determining if an LED is applicable. It has been found that simply comparing the $I-V$ characteristics of an LED at 4 and 300 K is a good means of determining if it will work at liquid helium temperatures. All the diodes tested show a positive shift in the knee voltage (where conduction dramatically increases) as the temperature is decreased. If the diode functions at low temperatures, then this shift will not be large ($<0.5$ V). If the diode does not function, however, the shift could be of the order of tens of volts. Another rule of thumb which seems to work fairly well is that the LEDs which have a voltage drop of 1.6 V or less at room temperature for a 20 mA drive current will probably work at 4 K. The LEDs tested in this study with voltage drops of 1.8 V or higher with a 20 mA drive current did not function at 4 K.

In summary, this work has shown that optoelectronic devices can be used as a viable source of heating at millikelvin temperatures. A thermally anchored optical fibre system has proven capable of generating heating from fractions of a nanowatt to 25 nW (the latter requiring a drive current of 10 mA to the LED). The 4 K stage can easily absorb any heating generated by the diode itself. Since the heat is transferred to the region of interest through an optical fibre, it is ideally suited to experiments with size constraints or which are sensitive to thermal contact.

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