Thermometer based on temperature dependence of shot noise in single barrier structure

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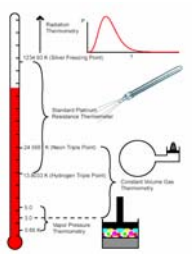
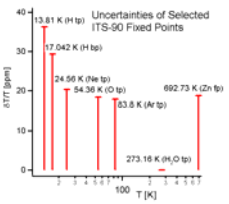
Thermometry

- Type of thermometers
  - Primary: operation principle is based on well understood physics
    e.g. ideal gas thermometer, nuclear orientation thermometer, noise thermometer
  - Secondary: needs to be calibrated from some outside standard
    e.g. resistive thermometers, vapor pressure thermometer
- Desirable characteristics for a thermometer
  - Wide usable temperature range
  - Fast
  - Primary
  - Easy and simple to use
  - Physically compact

Temperature scale (ITS-90)



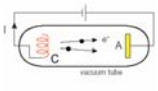
Methods for accurate temperature measurements at national metrology institutions



Fixed points for calibration

Noise in electronic devices

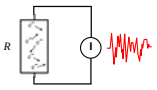
Shot noise Schottky (1918)



- Quantization of charge carriers
  → shot noise
- Magnitude of noise for vacuum tube

$$S_I(I) = 2eI$$

Thermal noise (Johnson noise)



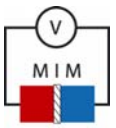
- Brownian motion of charge carriers
  → thermal noise
- Magnitude of noise for resistor *R*

$$S_I(R,T) = \frac{4k_BT}{R}$$

Noise thermometry

- Characteristics of noise thermometer
  - primary
  - electronic → physically compact
  - wide temperature range
- Thermal noise thermometry
  - absolute value of noise need to be measured
  - calibration of amplifier is difficult
  - relatively slow to get accurate value

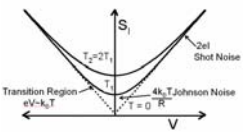
Shot noise and temperature

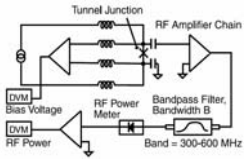


$eV \sim k_BT$

- When $eV \sim k_BT$, shot noise of a tunnel barrier depends on k_BT and bias voltage

$$S_I(V,T) = 2eGV\coth\left(\frac{eV}{2k_BT}\right)$$

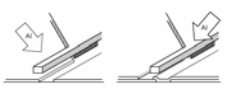




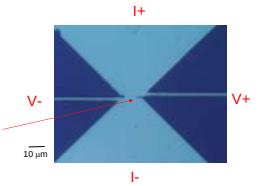
[Science **300**,1929 (2003) by Yale group]

Sample fabrication

- Formation of suspended e-beam resist bridge
  → Al/ AlOx/Al tunnel junction can be fabricated by two angle evaporation of Al

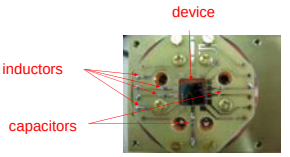


- Optical microscope image of fabricated tunnel junction device

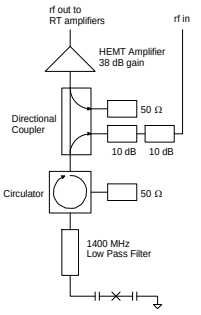


Design of sample holder

- dc lines are filtered by on-board inductors
- to prevent dc voltage from entering rf lines, blocking capacitors are used
- picture of sample and sample holder with surface mount capacitors and inductors

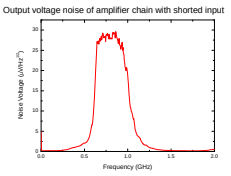


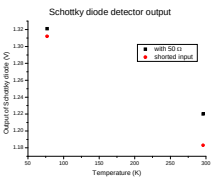
Rf setup at cryogenic temperatures



- Low temperature part of rf set up
- It is important to prevent outside interference from reaching the sample

Preliminary test of rf amp characteristics





- Signal with freq. between 650 and 950 MHz is amplified
- Schottky diode detects integrated rf power between 100 kHz and 2 GHz
- The output of Schottky diode depends on whether the input of amplifier is connected to 50 ohm or short

Conclusion

- A fast primary thermometer could be built from shot noise measurement of a tunnel junction, which may be useful for temperature metrology.
- Since shot noise can provide additional information on transport mechanism in electronic devices, the techniques developed in this experiments can be useful to investigate transport mechanisms in other electronic devices such as Josephson junction devices.