Low Temperature Amplifiers for Enhanced NMR Sensitivity for in-situ Applications

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Introduction

In order to realize the sensitivity needed for quantitative measurements of the quantum tunneling of $^3$He impurities in solid $^4$He in the temperature-pressure regime where so-called “supersolid” properties have been reported, we needed to develop low-temperature amplifiers that could be placed in close proximity to the NMR coil and operated in field and at temperatures below 100 mK.

Experimental

We have been developing a two-stage amplifier that consists of (i) a source follower circuit operating at very low temperatures and close to the NMR reception coil in a crossed-coil setup that matches the NMR receiver coil to a 50-ohm cryogenic cable, and (ii) a matching amplifier stage at 4K that feeds the NMR signal to a room temperature spectrometer. The reason for separating the stages is thermal. We used pseudomorphic high electron mobility transistors (pHEMTS) [1] because of (i) their high gain at low temperatures, and (ii) their planar geometry allowing us to orient them with the conduction plane parallel to the magnetic field to eliminate undesired Hall effects [2]. The disadvantage of the pHEMTs is the relatively high power dissipation. A single stage operating relatively close to cut-off generates almost 0.5 mW. We therefore allow the amplifier and receiver coil to be weakly anchored to the still of a dilution refrigerator while the sample (solid $^4$He with $^3$He impurities) is contained in a hermetic polycarbonate cell using sintered silver heat exchangers as a high thermal conductivity path to mK temperatures.

Results and Discussion

The noise temperature of the system was determined by measuring the total noise power of the source follower circuit followed by further amplification by 89dB and detection using a mixer driven at 2MHz corresponding to the resonant frequency of the NMR detection coil that was impedance matched to the input stage of the source follower circuit. The noise power was measured as a function of temperature down to liquid helium temperatures. The total noise figure of the input circuit was determined to be less than an effective noise temperature of less than 0.9 K.

Conclusions

Preliminary tests of the pHEMT amplifiers operating at helium temperatures have shown that one can match a high Q NMR receiver coil operating at low frequencies of 2MHz, thereby realizing ultra-high sensitivity needs for pulsed NMR studies in high fields. Extension to frequencies in the 100-400 MHz range should be straightforward and in some ways easier than the low frequency operation.

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References