Development of High-Frequency Millimeter Wave Techniques for Pulsed Fields

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Introduction

Electron spin resonance (ESR) and cyclotron resonance (CR) are vital in the study of electronic structure and magnetism of materials. For example, CR can yield the strength of electron-electron correlations via the dynamical mass, and determine the Fermi surface topology. However, very high magnetic fields are required to extend CR to heavy mass and/or disordered correlated-electron systems, and to cuprate superconductors, where the upper critical field must be exceeded. Similarly, magnetic fields ~ 100 T in conjunction with high-frequency ESR could access the magnetic interactions in highly anisotropic spin-gap materials and molecular quantum magnets, probe phase transitions in f-electron systems, and examine the electronic structure of organic radicals. Pulsed magnets are therefore required for such ultra-high-field CR and ESR experiments; but the resulting extreme environment presents challenges in resonant cavity and waveguide design.

Experimental

Prototype cavity and waveguide systems for pulsed fields and high frequencies have been constructed. The purpose of the current experiment is to optimize these components for use with the newly acquired MVNA extensions that provide frequency coverage up to 1 THz. As a first step, the cavities are being used in a 17 T superconductive magnet, to focus on aspects such as cavity performance, coupling holes, waveguide transitions and the influence of sample placement. Data were collected at many temperatures between 1.5 and 80 K.

Results and Discussion

The system chosen for study is $YbRh_2Si_2$. Previous (low-frequency) ESR measurements have indicated that a signal characteristic of the Kondo ion Yb^{3+} is observable in this system well below the Kondo temperature of 25 K. This is interesting, considering that thermodynamic measurements suggest that the EPR linewidth due to spin fluctuations should be approximately 10 T; if correct, this would broaden the resonance so much as to make it undetectable. Furthermore this system exhibits appreciable magnetoanisotropy evident in calculated g-factors from susceptibility measurements and low frequency EPR data: $g_{\perp} = 3.5$ (ab-plane) versus $g_{//} = 0.17$ (c-axis). For magnetic fields applied in the ab-plane, the field-dependent magnetization exhibits a change in slope that signifies a phase transition from a 4f itinerant state to a localized state (at about 10 T). Our unique capabilities, i.e. high magnetic fields and high frequencies, provide an excellent opportunity to study the spin-dynamics of both the localized state and the delocalized state through the phase transition. Both temperature dependent and frequency dependent ESR measurements have been performed at tens of closely-spaced frequencies giving resonances up to 9.5 T (371 GHz). These clearly reveal a systematic decrease in line intensity as the phase boundary is approached. Further studies will focus on detection of an ESR signal at and above the phase boundary, plus subsequent frequency, temperature and angle-dependent measurements.

Conclusions

The performance of the cavity and wavguide systems in combination with the MVNA extensions is very good, and has allowed a large region of previously unexplored field/temperature/frequency parameter space to be accessed in $YbRh_2Si_2$. Experiments continue, prior to a transfer to pulsed fields in the Spring.

Acknowledgements

This work was performed at the National High Magnetic Field Laboratory, which is supported by National Science Foundation (NSF) Cooperative Agreement No. DMR-1157490, the State of Florida, and the U.S. Department of Energy. The project is part of the DOE BES FWP “Science at 100 T”.