A study on coherent magnetic properties in Ferrimagnetic Insulator

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論　文　内　容　要　旨

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氏　　名	埋田　真樹	提出年	令和２年
学位論文の題　　目	A study on coherent magnetic properties in Ferrimagnetic Insulator （強磁性絶縁体におけるコヒーレント磁性物性の研究）		

論　文　目　次

A spin wave, a magnon, is elementary excitation in magnetically ordered states. Spin wave exhibits a variety of excitation modes reflecting their dispersion relations. A propagating spin wave carries spin angular momentum even in a magnetic insulator. Furthermore, the dispersion relation can be controlled by changing material, sample size, or direction of the applied external field. Controlling spin wave properties has attracted much attention in the field of spintronics due to the potential application to magnetic devices that can transmit, store, and process information using spin waves.

Recent advances in experimental techniques and understanding have led to various experiments for coherent spin transport phenomena, such as at the superconductor interface or spin waves in the planar cavity. In this thesis, we further examine this coherent spin dynamics via YIG coupled systems (superconductor in *Chapter 3* and cavity's mode in *Chapter 4*) to realize the coherent state. Below, we elaborate on these purposes and show the outline of this thesis.

Chapter 1 is devoted to a short overview of magnonics and spintronics. It provides the theoretical background for the coming discussion in the next chapter.

Chapter 2 describes the crystallographic properties of the sample, the sample fabrication and simulation processes, and the measurement techniques, including their physical backgrounds.

Chapter 3 describes spin dynamics in superconductor/YIG systems.

Spin dynamics in superconductors has been investigated mainly in terms of the temperature dependence of the nuclear-spin relaxation rate or AC conductivity in previous studies. The effect is known as a coherence effect. Here, we measured the temperature dependence of spin Seebeck effects (SSEs) in a NbN thin film/YIG bilayer system. Around the superconducting transition temperature, the SSE signal shows an anomalous peak structure, whereas the SSE signal becomes zero below the temperature. It cannot be explained by the normal SSEs in conventional paramagnetic metal/YIG systems. The result of a theoretical calculation based on the linear response theory well reproduces the experimental results. The result shows that spin current can be used as a probe for spin dynamics in superconductors.

Chapter 4 addresses the discovery of hybridization control between YIG and photons in planar resonators.

Magnons in a magnetic material can be coupled to cavity microwaves when their mode volumes overlap. In the strong coupling regime, it causes level repulsion and creates coherent hybridized states, called cavity-magnon-polaritons (CMPs). They manifest themselves even in the weak coupling regime. Among various resonators, a ring resonator is particularly suitable for coupling magnons in thin-films and microwaves concentrated near the resonator surface. They are relatively easily fabricated by lithography techniques, making it possible to design experiments. In this study, we investigated the control of the magnon-photon coupling strength between YIG film and an omega-shaped resonator by changing the applied magnetic field angles and strengths. We found that the effective coupling exhibits a pronounced change around a critical angle at which nonlinear magnetization dynamics is switched on. It enables us to control the coupling between a microwave and magnetization dynamics.

Chapter 5 summarizes our results and comments on their importance.

We performed a series of measurements of magnetization dynamics in YIG-combined systems exhibiting coherent phenomena of spin transport or dynamics. The results obtained in this study is important in the field of physics of coherent dynamics in magnetically ordered materials. First, the observed coherence peak in NbN/YIG implies that the coherence effect, which has been mainly studied from the viewpoint of nuclear magnetic relaxation in bulk superconductors, can also be detected by spin current and inverse spin Hall effect, showing the versatility of spin current as a probe of spin dynamics. Next, the Observed abrupt change in the magnon-photon coupling strength suggests that nonlinear magnetization dynamics can be used for controlling the magnon-photon coupling in small magnets. A Planar resonator is particularly suitable for coupling magnons in thin-films and photons concentrated near the resonator surface. They are relatively easily fabricated by lithography techniques, making it possible to design experiments in a variety of dimensions and shapes. Our result expands the new physics and develops the technique of planar resonators to realize the new coherently coupled state.

別　紙

論文審査の結果の要旨

磁性体における磁気ダイナミクスと電子や光子の結合はスピントロニクスの基本要素である。従来、これらの系の実験は室温且つ極めて結合の弱い系で行われていた。しかし近年、電子のコヒーレンスが高い超伝導を利用したスピントロニクス現象や、マイクロ波光子を共振器に閉じ込めて磁性体と相互作用させることによる結合の強化が実現できるようになった。埋田真樹氏提出の論文は、超伝導 NbN/フェリ磁性 YIG 系の輸送特性、及び YIG 磁化ダイナミクスとリング型マイクロ波共振器の結合した系の磁気特性を調べたものである。

NbN/ YIG 接合に熱流を与えたとき、NbN が常伝導相では良く知られたスピンゼーベック効果が表れる。ところが NbN の超伝導転移点近傍の熱誘起起電力を精密に調べると、転移点直上で鋭いピーク構造が現れることを見出した。超伝導転移温度近傍では、電子の位相秩序形成によるコヒーレンス効果が諸物性に現れ、典型的には核スピン緩和の準粒子コヒーレンスピークとして知られている。近年、同様の準粒子コヒーレンス効果が超伝導体/磁性体界面のスピン輸送係数を増大させることが理論的に提案されており、理論と比較検討することで、実験的に観測されたピーク構造がこの準粒子コヒーレンス効果と解釈できることを示した。

更に、リング型マイクロ波共振器に YIG 薄膜を取り付けた構造を作製し、共振器モードと YIG スピン波モードの振動数が一致する点でマイクロ波吸収強度の変調が生じ、この変調が磁場方向に強く依存することを見出した。これは、共振器中のマイクロ波と磁化歳差運動との比較的強い結合が実現され、この結合が非線形マグノン散乱効果により変調されることを示しており、共振器中のマイクロ波と磁気ダイナミクスの結合を非線形マグノン効果によって制御できることを明らかにしたものである。

埋田真樹氏提出の論文は、超伝導体/磁性体スピン伝導における準粒子コヒーレンス効果及び、非線形マグノン効果を用いた共振器マイクロ波・磁化ダイナミクス結合変調を見出したものであり、提出者の埋田真樹氏が自立して研究活動を行うに必要な高度の研究能力と学識を有することを示すと判断できる。したがって、埋田真樹氏提出の博士論文は，博士（理学）の学位論文として合格と認める。