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学位論文題目	Construction of an apparatus with permanent magnet flipper for magnetic circular dichroism (MCD) measurements and research on MCD of Ni and Gd thin films
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論文内容の要旨

The measurement of MCD due to core electron excitation clarifies the degrees of symmetry breaking of orbital and spin momentums localized at a constituent atom in a magnetically ordered material. The degrees of symmetry breaking of orbital and spin momentums are one of the most important information for better understanding of ferromagnetic systems.

In this research an apparatus for measurement of MCD was constructed and the MCDs on ferromagnetic Ni and Gd thin films were measured in the vicinity of the 3p-3d transition for Ni and the 4d-4f transition for Gd, respectively. The experiments have been performed at the BL-28A of the Photon Factory.

Ferromagnetic Gd metal is a material where the 4f orbital momentum vanishes due to the occupation in highly localized 4f orbital according to the Hund's rule and the magnetic moment is attributed to only the spin momentum of 4f electrons, while the ferromagnetism of Ni metal is explained by "itinerant" or "localized" models which should be unified in the future studies. In analysis of the MCD of rare earth metals the atomic model is used because of the localization of 4f orbital. The comparison of MCDs between Ni and Gd will clarify the difference between 3d electron system and highly localized 4f electron system.

The basic design principles for the apparatus are as follows.

- (1) The apparatus must be an ultrahigh vacuum system which is needed to be connected to a VUV beam line and to prevent samples from being degraded by residual gases.
- (2) The sample has to be a thin film for VUV radiation to go through with appropriate absorption. So as to get thin film the apparatus must be equipped with an evaporation system such as an electron-gun with a shutter and a quartz thickness monitor. After a thin film is prepared the MCD signals of the sample must be measured as soon as

possible in order to prevent the sample from being degraded by residual gases.

(3) A magnet which can generate a static magnetic field high enough to saturate the magnetic moment of the sample is needed. The magnet is required to be compatible with ultrahigh vacuum.

In the apparatus a permanent magnet flipper is adopted so as to change the magnetic field in a few second. Then the permanent magnet flipper makes it possible to measure MCD at each photon energy without any systematic error caused by instability of light source and especially the influence of degradation of the sample by residual gases.

In BL-28 an helical undulator was installed as a circularly polarized light source. The beam axis is identified in such a way that the highest energy peak position of the fundamental harmonic component was observed and the ratio of the fundamental and the second order harmonic components was maximized. This procedure of identification of the beam axis without confirmation of the degree of circular polarization is also applicable to circular polarized radiation sources emitting photons higher than 300 eV. In fact in the photon energy region higher than 300 eV measurement of the degree of circular polarization is very difficult because of lack of an appropriate polarizer or analyzer.

The monochromator installed at BL-28A has constant deviation optics. The MCDs were measured with the energy resolution better than 70 meV.

Apparent MCD was observed in 3p-3d transition region of Ni. In the lower energy range MCD with the positive sign was observed. Here the MCD is defined by $(\mu_L - \mu_R)/(\mu_L + \mu_R)$, where μ_R and μ_L are the absorption coefficients for right- and left-circularly polarized light, respectively. The largest structure was observed with the negative sign at the position where the $3p_{3/2}$ -3d transition occurs, while at the $3p_{1/2}$ -3d transition energy the structure was much smaller and with the positive sign. These structures were not due to spurious signal generated by the influence of the magnetic field on the detectors or magnetic field error on the sample etc., because the signs of all these structures were confirmed to reverse and their absolute values were almost conserved when the helicity of circular polarization was changed.

The structures observed at the $3p_{3/2}$ -3d transition and at the $3p_{1/2}$ -3d

transition are different from those predicted by Erskine and Stern, but are qualitatively consistent with the results calculated by Yoshida and Jo. This fact suggests that the orbital momentum of 3d electron of Ni also contributes to the magnetic moment as well as the 3d majority spin. In the calculation the difference in contribution to MCD between $3p_{3/2}$ -3d and $3p_{1/2}$ -3d transitions directly reflects the extent of LS coupling of 3d electron.

The magnetic field of the permanent magnet flipper was too small to saturate the magnetic moment of Gd thin film to the normal direction of the film surface. In spite of incomplete magnetic saturation, new physical property about the MCD of Gd was found as well as in completely saturated Ni.

There is extended MCD in Gd in the energy region higher than the 4d-4f giant resonance. And there is also extended MCD in Ni in the energy region lower than the 3p-3d giant resonance. The extended MCD of Ni does not appear in both the result of calculation by Erskine and Stern, and that by Yoshida and Jo. In these calculations only the 3p-3d transition was taken into account. In the energy region of 3p-3d transition for Ni and 4d-4f transition for Gd there are 3d-ef and 4f-continuum transitions, respectively. Here we should take into account the Fano effect for the interference of a discrete excited state with a continuum through super Coster-Kronig transition. The Fano effect causes the broad and asymmetric profiles of absorption spectrum, which may give rise to the extended MCD. Especially for Ni in addition to the Fano effect there is another possibility which causes the extended MCD. The symmetry breaking of the orbital momentum of 3d electron of Ni may also give rise to the extended MCD with the positive sign through 3d-ef transition.

In Gd the extended MCD due to 4f-continuum transition does not occur because there is no symmetry breaking of the orbital momentum of 4f electron. Very recently Kotani et al. calculated the MCD for 4d-4f transition in Gd including the Fano effect. The shape of the observed MCD is close to the calculated one. The extended MCD in 4d-4f transition region of Gd is also explained by the Fano effect.

論文の審査結果の要旨

武藤貞嗣の論文にまとめられた研究は、永久磁石を用いた磁場変調装置を組み込んだ光電測光装置を製作し、それを用いてNi及びGd薄膜について磁気円二色性を測定したものである。

まず、永久磁石を用いた磁場変調装置は、アンジュレーター用の磁石にヒントを得たものであるが、世界の例のない、ユニークな試みである。この磁石を直線運動させることにより数秒という短時間で磁場を反転させることができるので、蓄積リング内の陽電子ビームの遅い不安定性の影響を取り除くことができる。実際にこの研究において、他の原因に起因して生ずる見かけ上の磁気円二色性は、R.M.S.で0.01%以下であることが論文内に報告されている。

また、活性な物質を蒸着して薄膜を得るためには、測定装置全体が超高真空仕様でなければならないが、永久磁石は、それほど高温にベークできないという制約がある。彼は、この問題を永久磁石がベーク中には、バルブで隔てられた副チェンバーに待避する機構を持たせることで解決しており、測定時の真空は 2×10^{-10} Torr以下、条件の良いときは 5×10^{-11} Torrという超高真空を実現している。このことは、測定された薄膜試料の信頼性を非常に高めている。

さらに挿入光源からの円偏光を利用するには、いかにして光軸中心をとらえるかが極めて重要であるが、彼はアンジュレーター放射の特性を利用した、系統的なアルゴリズムを見出し、中心軸を捉えることに成功している。この方法は、直接に円偏光度を測定することが困難であるような、300 eV以上の領域にも適用可能であり、波及効果が大い。

Ni及びGd薄膜の磁気円二色性も世界初のデータであるが何度も実験を繰り返して再現性をチェックし極めて信頼性の高いデータを得た上で理論との比較を試みている。特に、データの解釈においてFano効果の重要性を指摘した初めての実験的研究である。

以上のごとく、永久磁石を用いた磁場変調のアイデア、超高真空の実現、円偏光の中心軸の取り込みのアルゴリズム、Ni及びGd薄膜についての磁気円二色性について従来にない、新しい知見を与えており、博士論文として十分な内容をもっていると結論した。