Al/Si(111) 表面上の Co ナノ量子ドットの磁性研究

Study of the magnetism of Co quantum nano-dots fabricated on Al/Si(111) surface

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Si(111)7x7 清浄表面上に Al を吸着することによって作成した Al クラスターアレイ表面上に Co ナノ量子ドットを作成した。Co ナノ量子ドットについて Co 2p 内殻吸収領域の吸収と磁気円二色性スペクトルを観測し，その磁性について調べた。その結果，三角形をした小さいナノ量子ドットの示す Co L23 吸収スペクトルは Co3+の特徴を反映していたが，比較的サイズの大きい丸形のナノドットは Co 2+の特徴を持っていることが分かった。XMCD スペクトルからは，どちらの Co ナノ量子ドットも顕著な Co3d 電子の軌道磁気モーメントの寄与があることが明らかになった。

Co nano-dots with different shapes and sizes have been fabricated on high quality ordered Al nano-dot arrays on Si(111)-7x7 surface. We have measured soft X-ray absorption spectra (XAS) and X-ray magnetic circular dichroism (XMCD) spectra in the Co 2p core excitation region of the Co nano-dots. The multiplet fine structures of the XAS spectra indicate there is Co3+ contribution in smaller Co nano-dots with triangle shape, whereas, larger Co nano-dots have some Co2+ character. XMCD spectra show the orbital magnetic moment contribution is remarkably large in both kinds of Co quantum nano-dots.

Magnetic quantum nano-dots attract growing interest because of the great potential applications in the fields of high-density data storage and spin electronic devices. Recently, Jia *et al.* found that a high quality ordered Al nano-dot array as shown in Fig.1(a) could be prepared on Si(111)-(7x7) surface and the array exhibit a remarkable thermal stability that it becomes an ideal template for growing magnetic quantum nano-dots [1].

In this work, 0.24 ML Al had been evaporated onto a well ordered Si(111)-7x7 surface. Subsequently, Co quantum nano-dots with different sizes and shapes were deposited on the template by delicately controlling substrate temperature and Co evaporation rate. Au film with 2 nm thickness was coated on the Co nano-dots to prevent them from oxidation.

As observed from STM images, shown in Fig.2 (a) and (b), the Co nano-dots in both

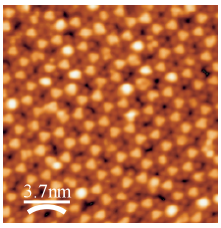

Fig.1: STM image of ordered Al nano-dot array onSi(111)-7x7 surface.

triangle and round shapes reside on top of the ordered Al cluster arrays. The Co nano-dots with triangle shapes have the same orientation. Although their lateral lengths range from 2 to 6 nm, further study shows that about 80% of the Co nano-dots have a uniform size of 5.4 nm, which is twice as large as the size of the Si(111)-7x7 unit cell [2]. Correspondingly, the round nano-dots have a larger size of about 10~15 nm. The most remarkable feature of these Co nano-dots is their uniform constant height of 2 monolayers. The physical origin of the magic height (2 ML constant height) remains unclear.

The lineshape of the *L*-edge XAS is a fingerprint for the *d*-state configuration, whereas XMCD yields the spin and orbital magnetic moments via well-known sum rules [3, 4] in an element specific manner. We have performed XAS and XMCD measurement of the Co quantum nano-dots at BL-25SU of SPring-8. The measurements were done by means of a total photoelectron yield method.

The Co L_{23} XAS and XMCD spectra of the Co quantum nano-dots are shown in Fig.3. We have observed several fine structures at the L_3 edge of the Co L_{23} XAS spectra. For Co nano-dots in triangle shape, the XAS lineshape is very asymmetric. The multiplet fine structures (A_0, B_0), observed on the high energy side of the main peak (C_0), can be attributed to Co^{3+} in an octahedral environment [5]. However, for Co nano-dots in round shape, there are also very clear multiplet fine structures (A, B) appear also on the low energy side of the main peak (C), which indicate Co^{2+} character in the present Co nano-dots [5].

Clear XMCD shown in the lower part of Fig.3 (a) and (b) were observed. One finds each fine structure in the XAS spectra is observed to be presented in the XMCD spectra at Co L_3 edge. Compared to the strong amplitude at the L_3 edge, the peak with positive sign at the L_2 edge is very small. That means the orbital magnetic moment contribution is very large in these Co quantum nano-dots. Following the well-known method developed by Chen *et al.* [6], we successfully estimated $m_L/(m_S+7m_T)$ = 0.37 (triangle shape) and 0.49 (round shape) for Co nano-dots with different sizes and shapes, respectively. Compared with the value of 0.1 for bulk Co, the remarkably improved contribution of orbital magnetic moment must be connected to both size effect of Co nano-dots and interface interactions between Co and Al underlayer.

The temperature dependence of the Co XMCD spectra for Co nano-dots in round shape was also measured. We clearly found that the integrated XMCD intensity decreased rapidly with increasing temperature, which is not shown here.

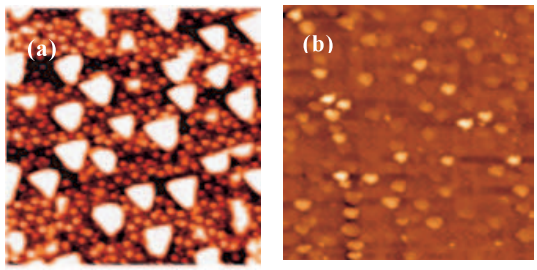

Fig.2: The observed STM images (a) Co nano-dots in a triangle shape reside. Most of the Co nano-dots have a uniform lateral length of 5.4 nm. (40 nm x 40 nm) (b) Co nano-dots with a diameter of 10~15 nm in a round shape. (250 nm x 250 nm) All of the Co nano-dots have a constant height of 2 ML.

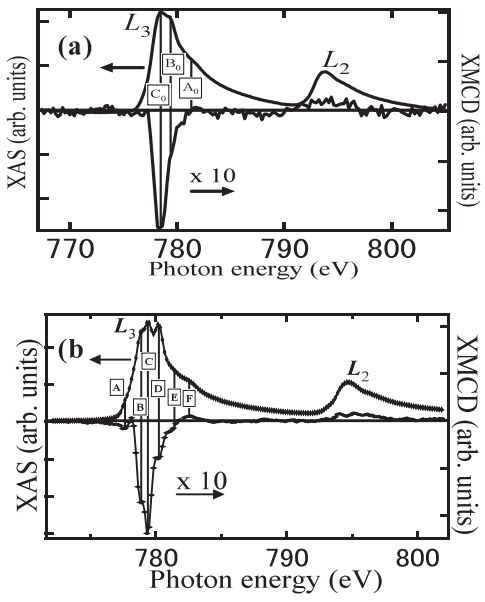

Fig. 3: Co L_{23} XAS and XMCD spectra (a) Co nano-dots in triangle shape (B=1.4 T, T= 43 K) (b) Co nano-dots inround shape (B=1.9 T, T= 27 K)

References

1) J. F. Jia et al., Appl. Phys. Lett. **80**, (2002) 3186.

2) Pan et al., Submitted to Science.

3) B. T. Thole et al., Phys. Rev. Lett. **68**, (1992) 1943.

4) P. Carra et al., Phys. Rev. Lett. **70**, (1993) 694.

5) F. M. F. de Groot et al., Phys. Rev. B **42**, (1990) 5459.

6) C. T. Chen et al., Phys. Rev. Lett. **75**, (1995) 152.