

発光分光による 電場印加下の電子状態研究

広島大院理 中島伸夫

磯濱陽一、渡辺剛基、圓山裕

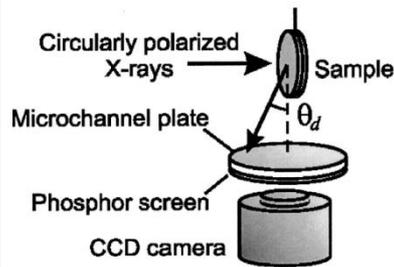
手塚泰久

中村文彦、坂木麻里子、木村有作

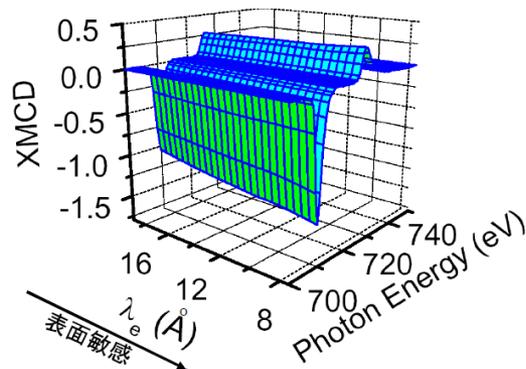
外場印加下での放射光実験

磁場

MCD



Fe/Cu(100)



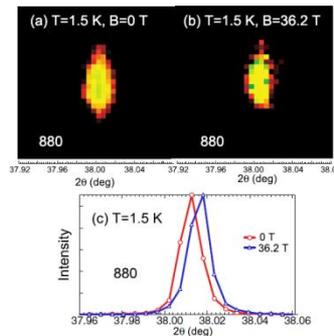
RSXS

Coming soon!

J. Okamoto *et al.*

K. Amemiya *et al.* Appl. Phys. Lett. 84 (2004) 936.

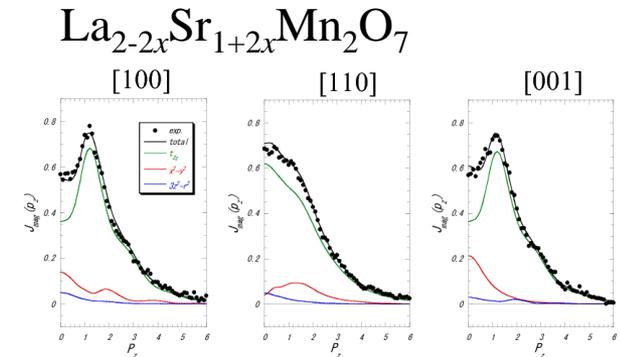
XRD



Y. Narumi *et al.*

J. Phys. Soc. Jpn. 78 (2009) 043702.

MCP

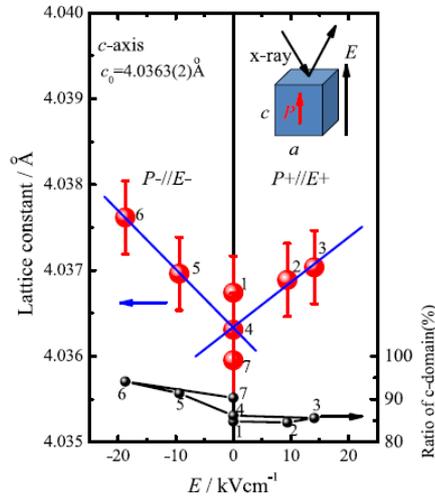
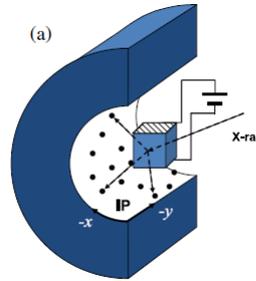


A. Koizumi *et al.* Phys. Rev. Lett. 86 (2001) 5589.

外場印加下での放射光実験

電場

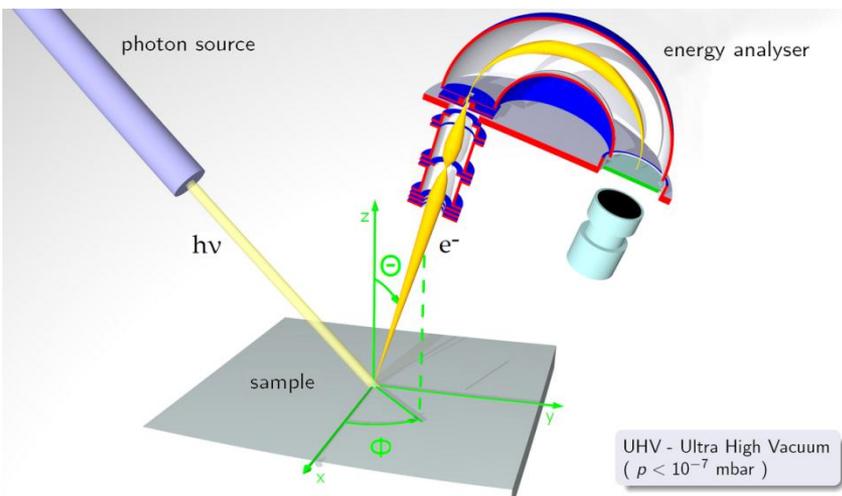
XRD



R. Tazaki *et al.* J. Phys: Cond. Matter. 21 (2009) 215903.

- 近接作用的な場であるために、試料周りの制約が困難
- 摂動の効果が（磁場に比べて）解釈困難
- 電子系よりは、格子系に作用する

Photoemission spectroscopy

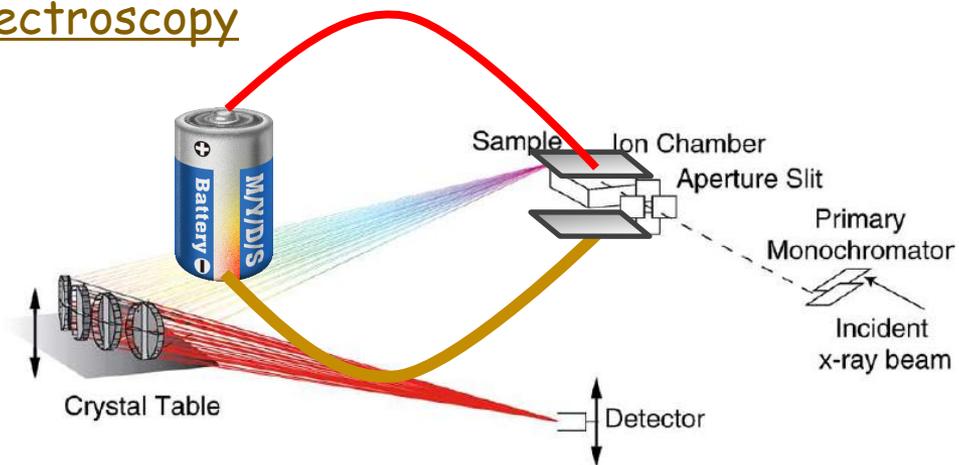
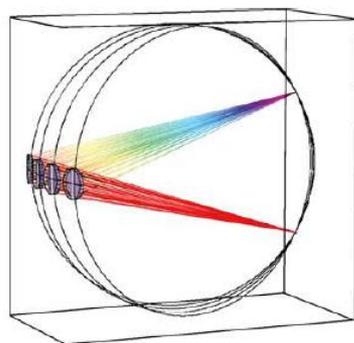


電子検出法ゆえ、、、
電場はじゃま物！



誘電体などの絶縁体もOK

X-ray emission spectroscopy

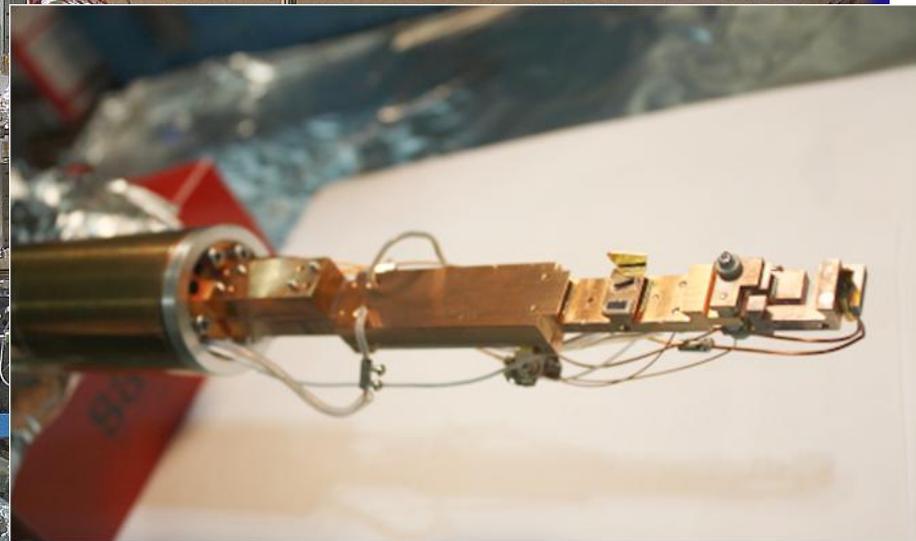
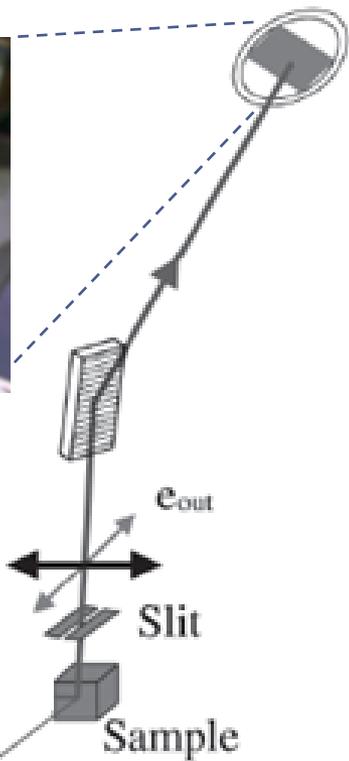
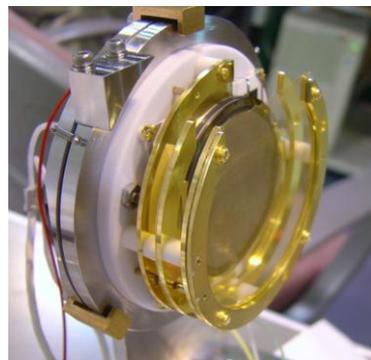


測定例 その1

電場に誘起された Ca_2RuO_4 の
絶縁体金属転移

軟X線発光分光 -BL2C-

電場印加用試料デッキの作製



SR

e_{in}

e_{out}

Slit

Sample

~2 kV - 5kV

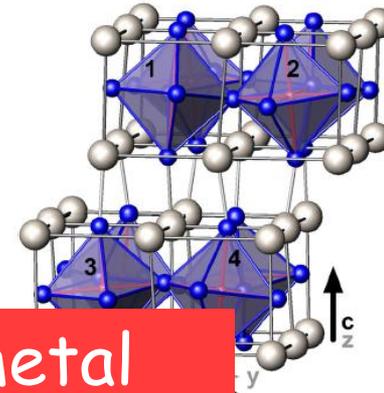


CRO

Almina

Sample -Ca₂RuO₄-

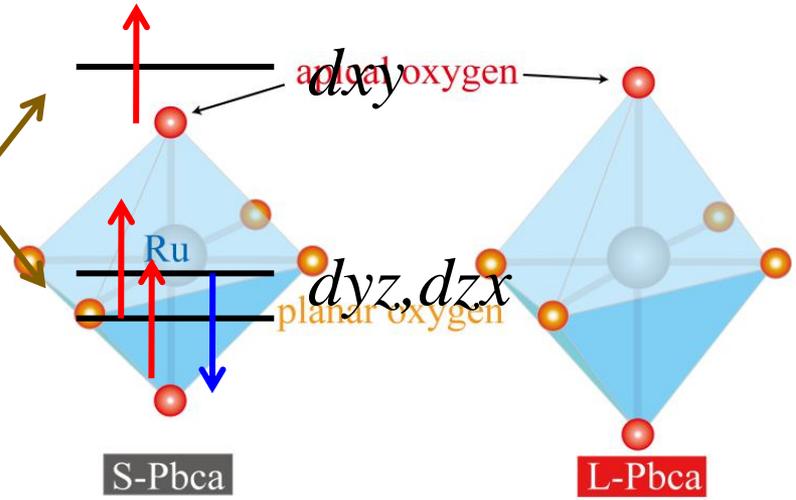
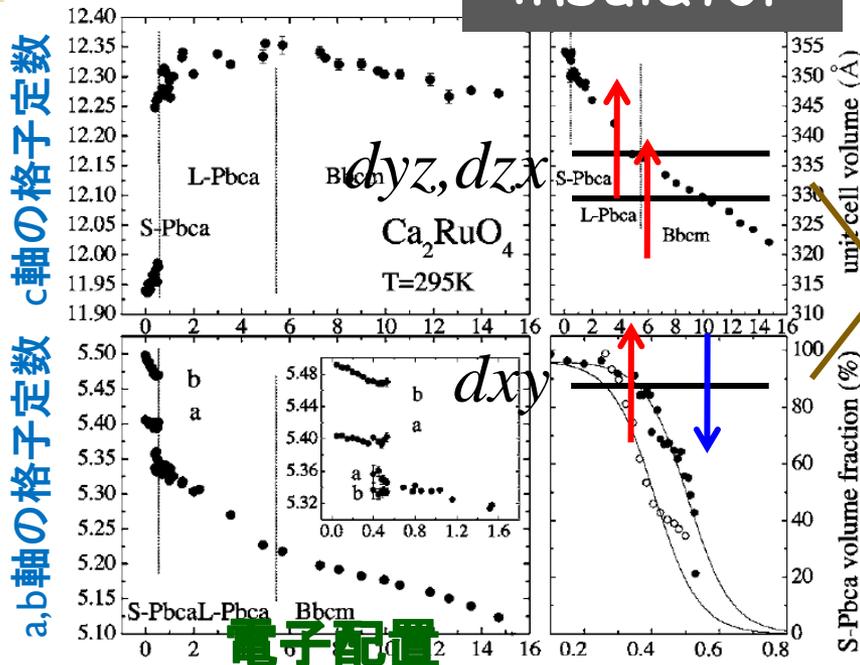
層状ペロブスカイト
c軸周りに回転、b軸周りに傾斜



insulator

metal

E. Gorelov et al., PRL. 104(2010)226401

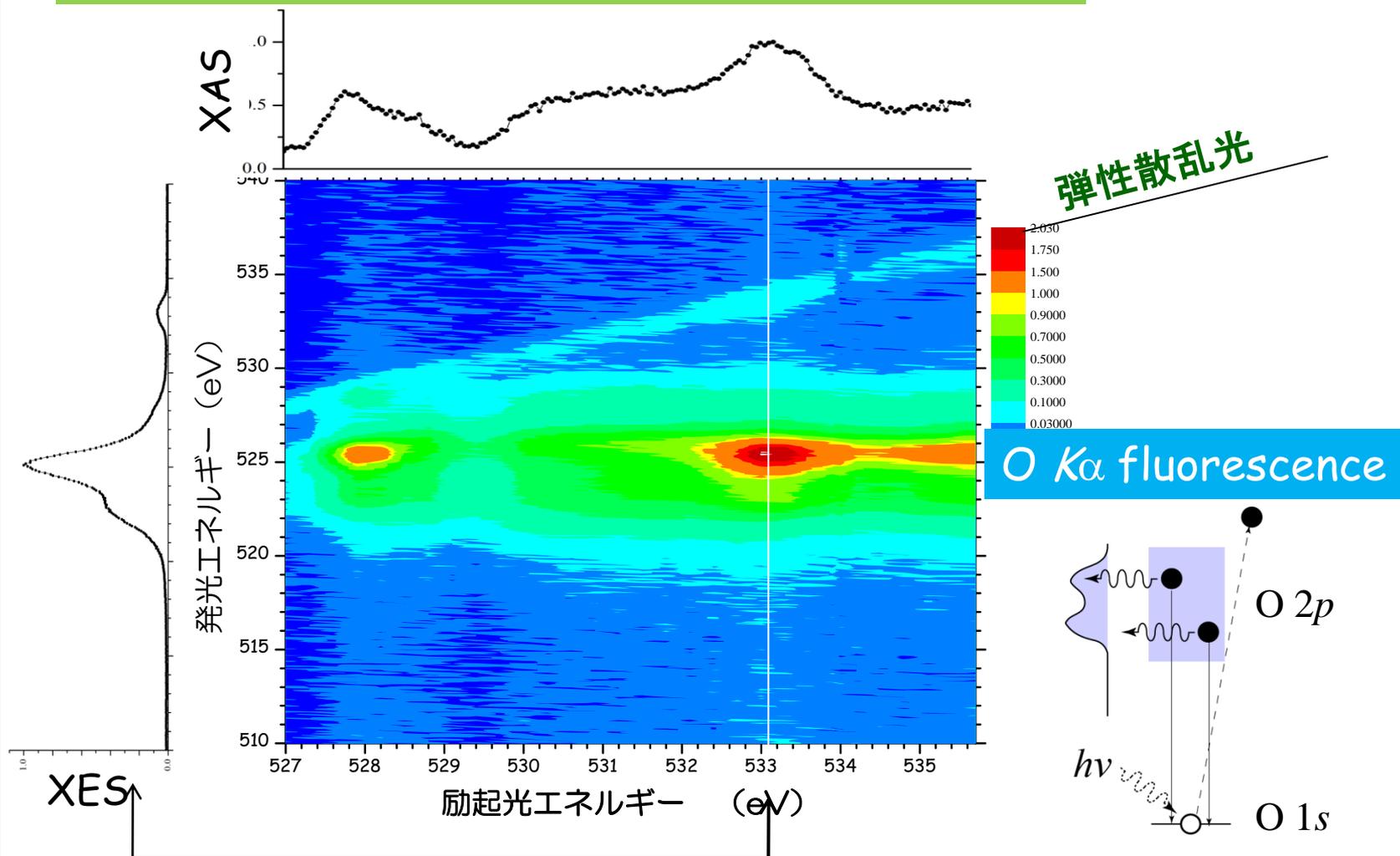


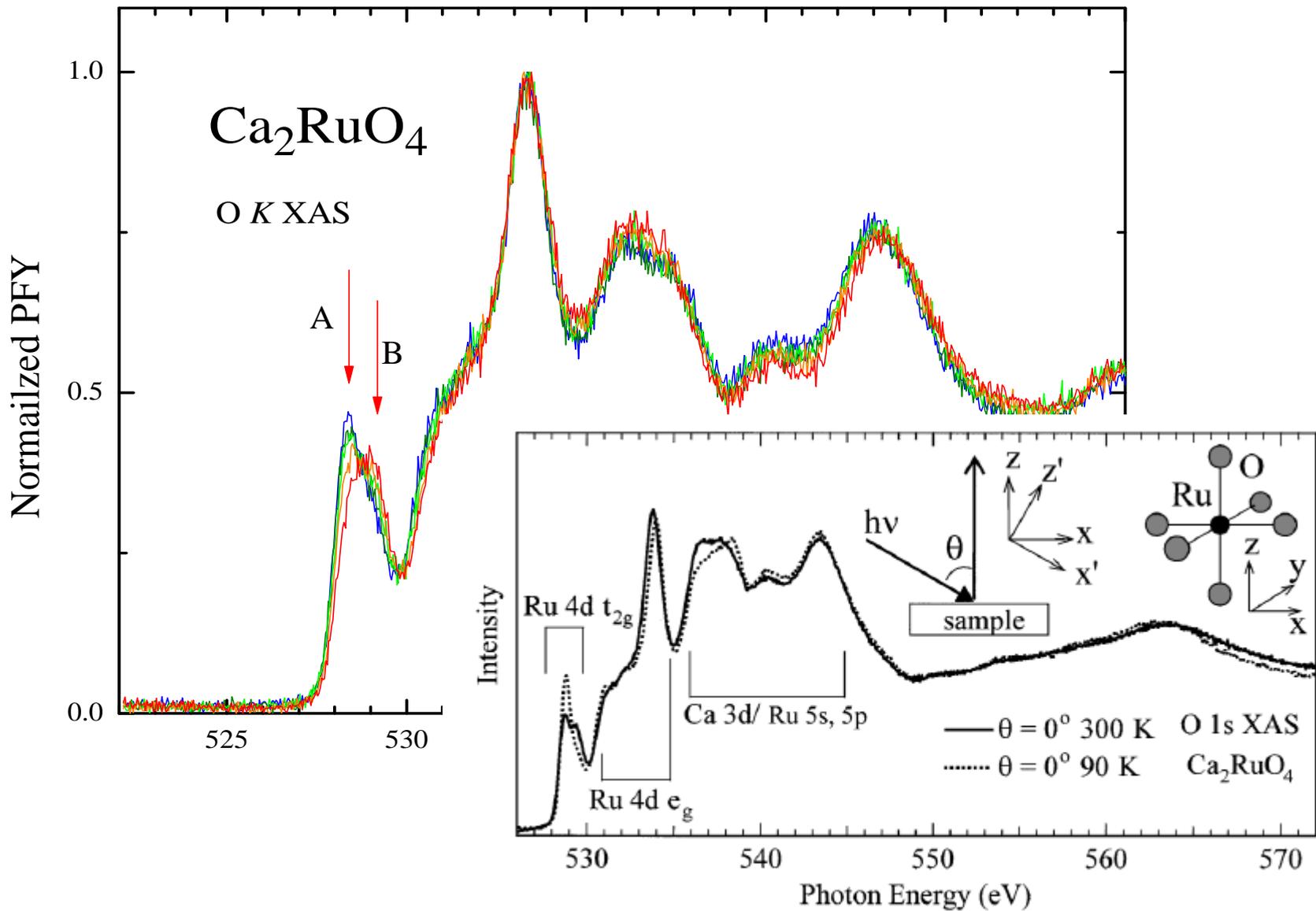
電子配置
Ru⁴⁺ 4d⁴ t_{2g}³ e_g⁰

P. Steffens et al., PRB 72, 094104 (2005)

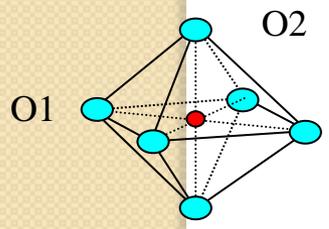
Results

O $K\alpha$ 発光スペクトルの二次元マップ



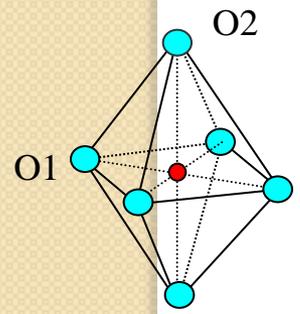


Insulator (*S-Pbca* flattened)



(Ru-O2 < Ru-O1) 2.5%
 $\uparrow\uparrow$ $d_{xz} d_{yz}$ (apical)
 $\uparrow\downarrow$ d_{xy} (in-plane)

Metal (*L-Pbca*)

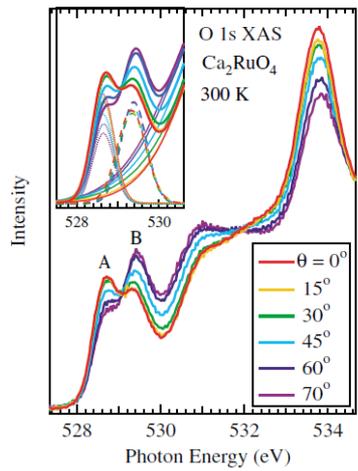
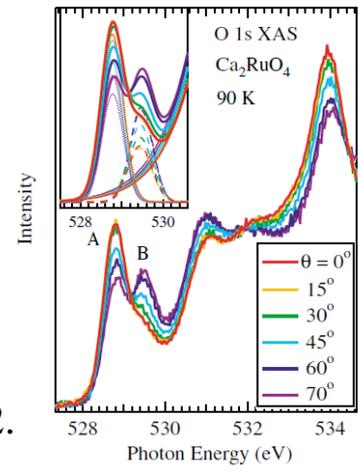
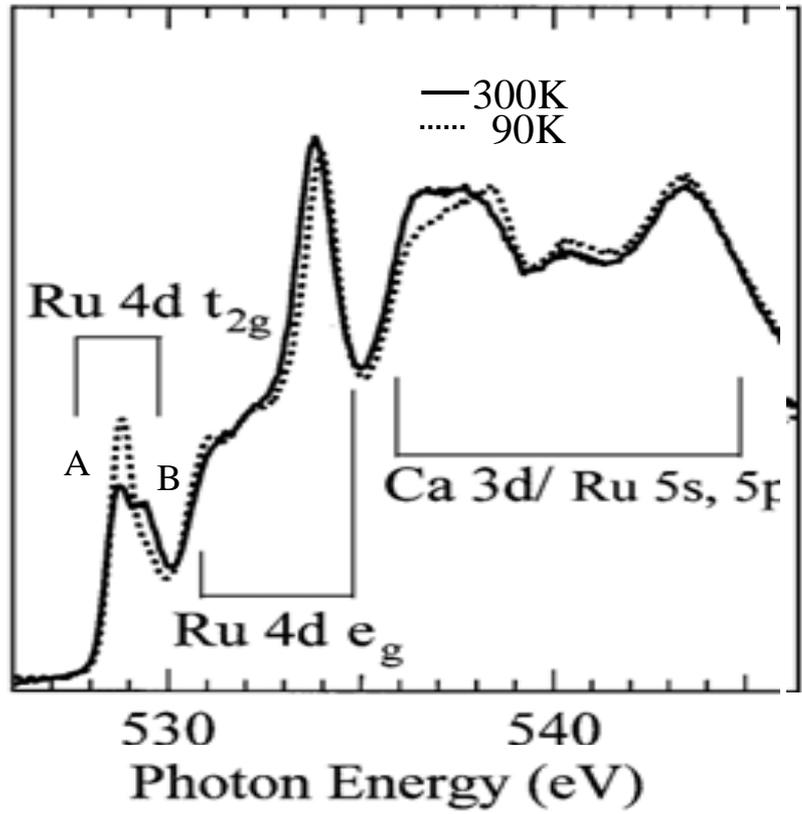


(Ru-O1 < Ru-O2)
 \uparrow d_{xy}
 $\uparrow\uparrow\downarrow$ $d_{xz} d_{yz}$

A. Apical
 B. In-plane

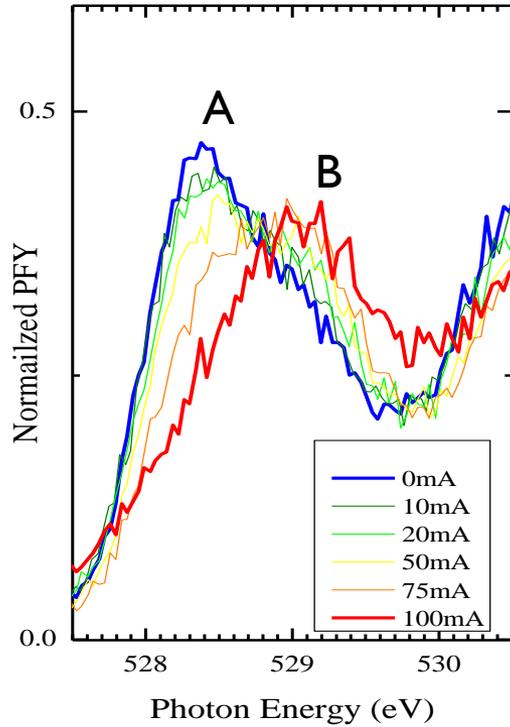
円偏光
 • apical $\frac{1}{2}(\cos^2\theta n_{yz/zx})$
 • In-plane $\frac{1}{2}(\cos^2\theta+1)n_{xy} + \frac{1}{2}\sin^2\theta n_{yz/zx}$

〔高温&高角度では、apical成分減少〕

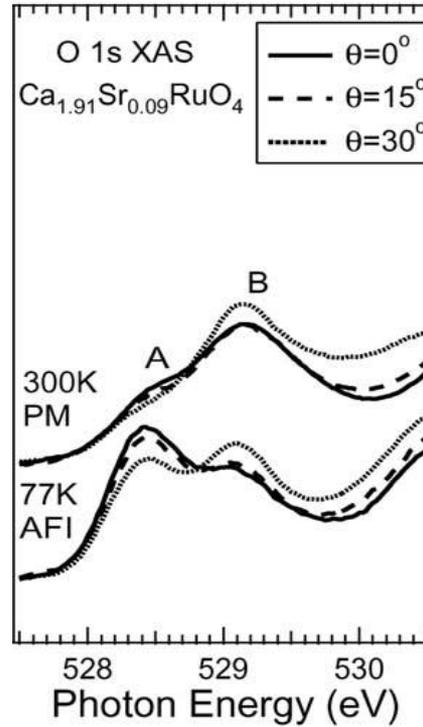


金属-絶縁体転移と電子状態

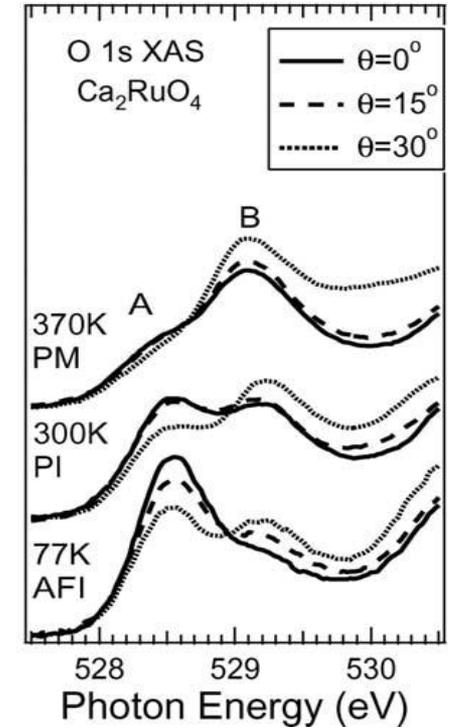
電場



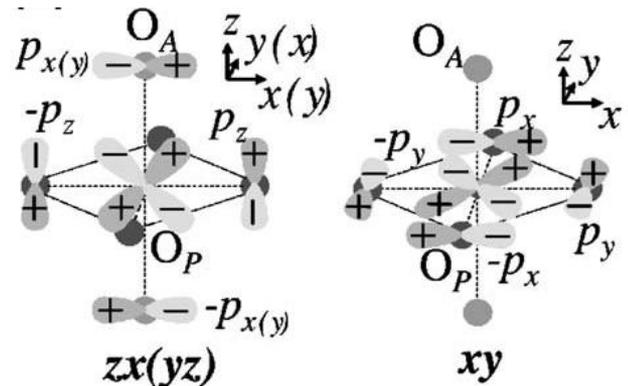
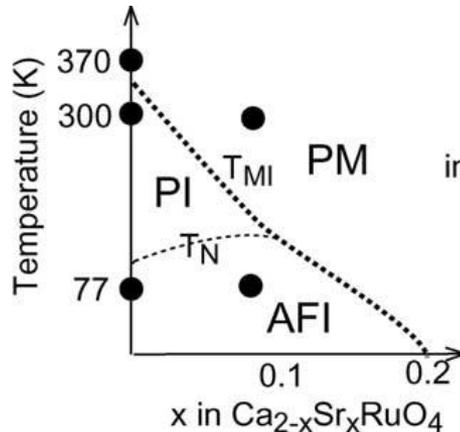
元素置換

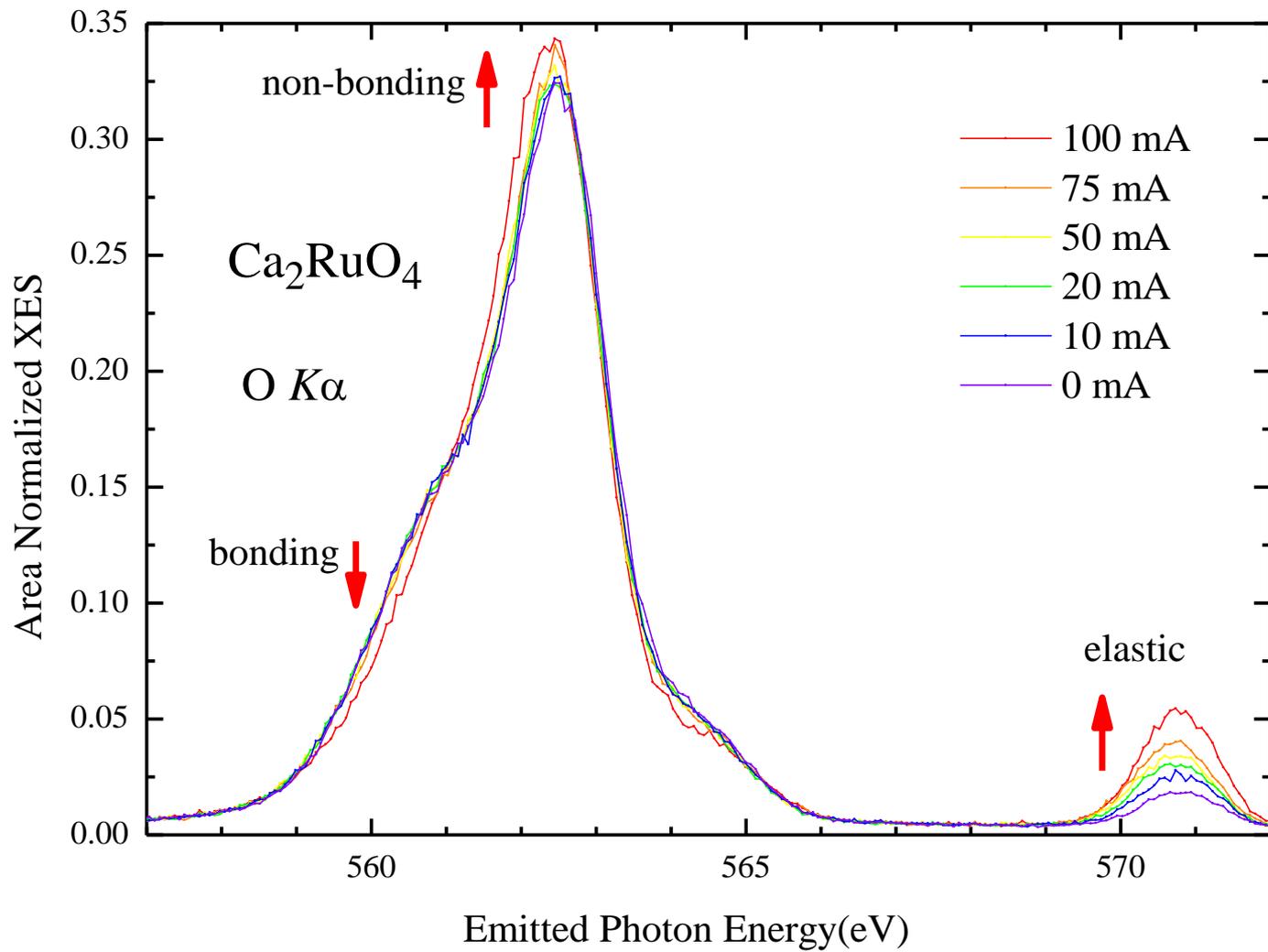


温度



A : apical ; $zx(yz)$
 B : in-plane; xy





→ 入射偏光依存性のXES測定が必要！

測定例 その2

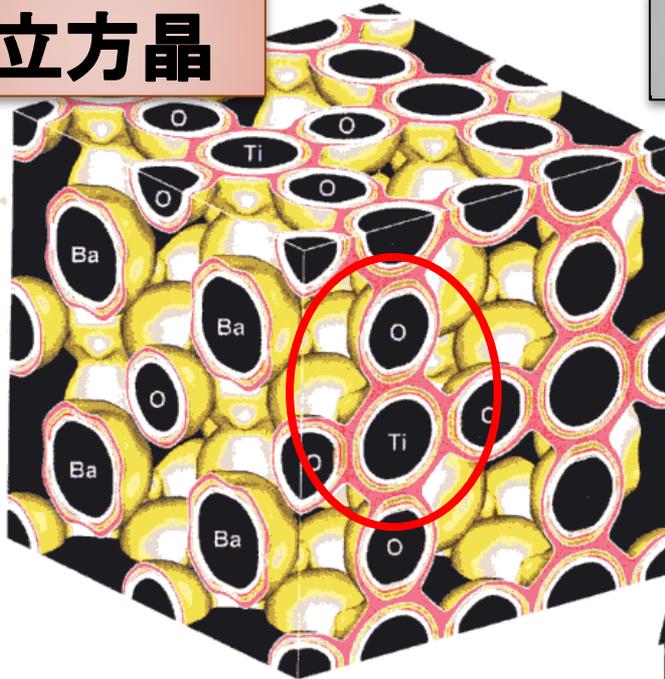
典型強誘電体 BaTiO_3 の
局所分極の電場応答

BaTiO₃

(Powder XRD)

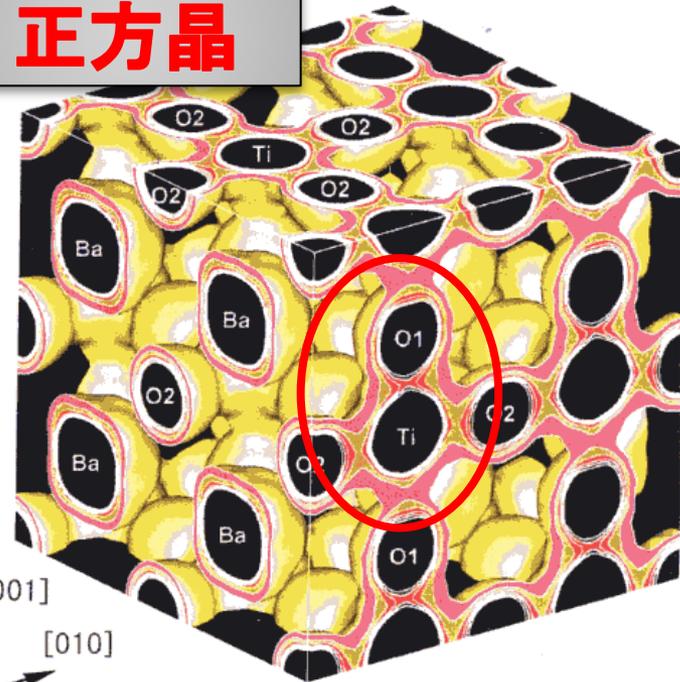
XRD:MEM/Rietveld 電子密度分布

立方晶



$T > T_C$ [K]

正方晶

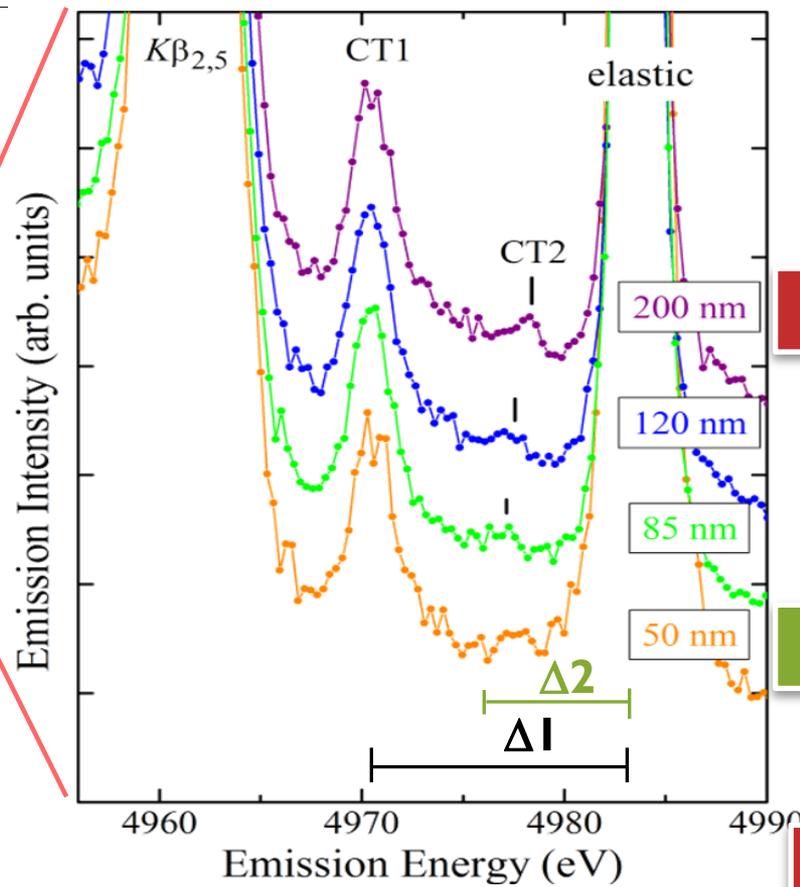
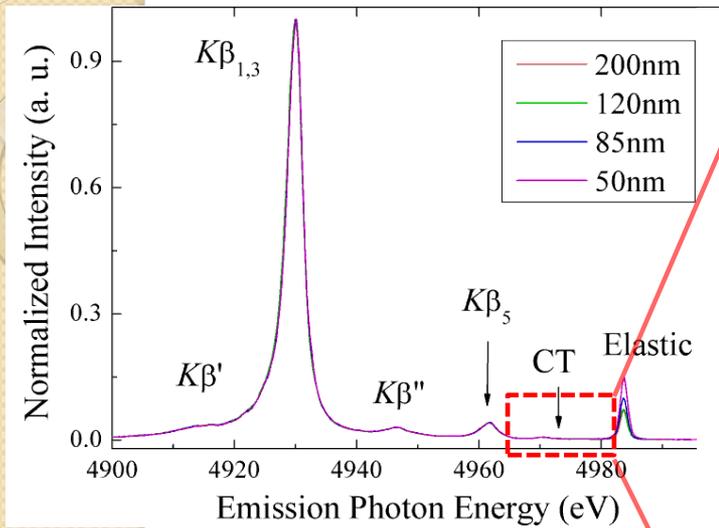


$T=300$ [K]

Y. Kuroiwa *et al.*, Phys. Rev. Lett. 87 (2001) 217601

XRD → 平均構造

RXESスペクトル例 - BaTiO₃ nano particles-

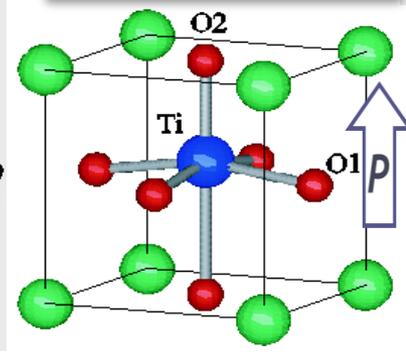
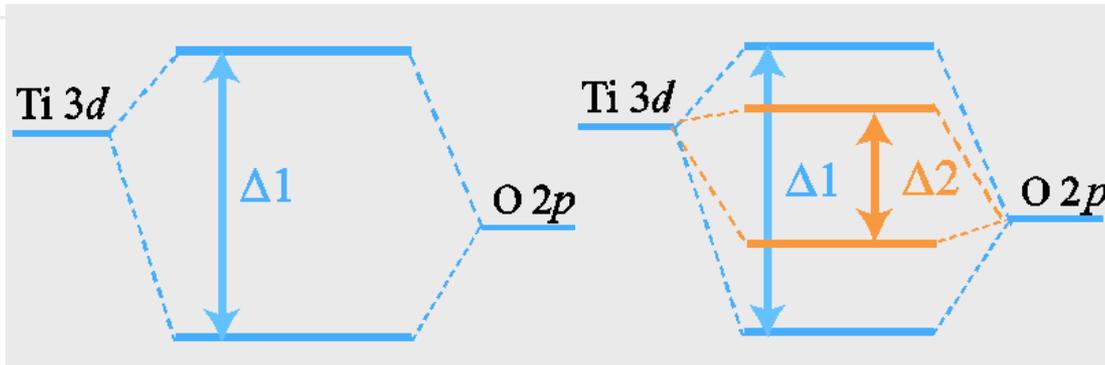
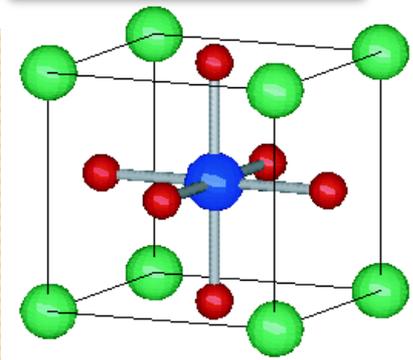


強誘電相

常誘電相

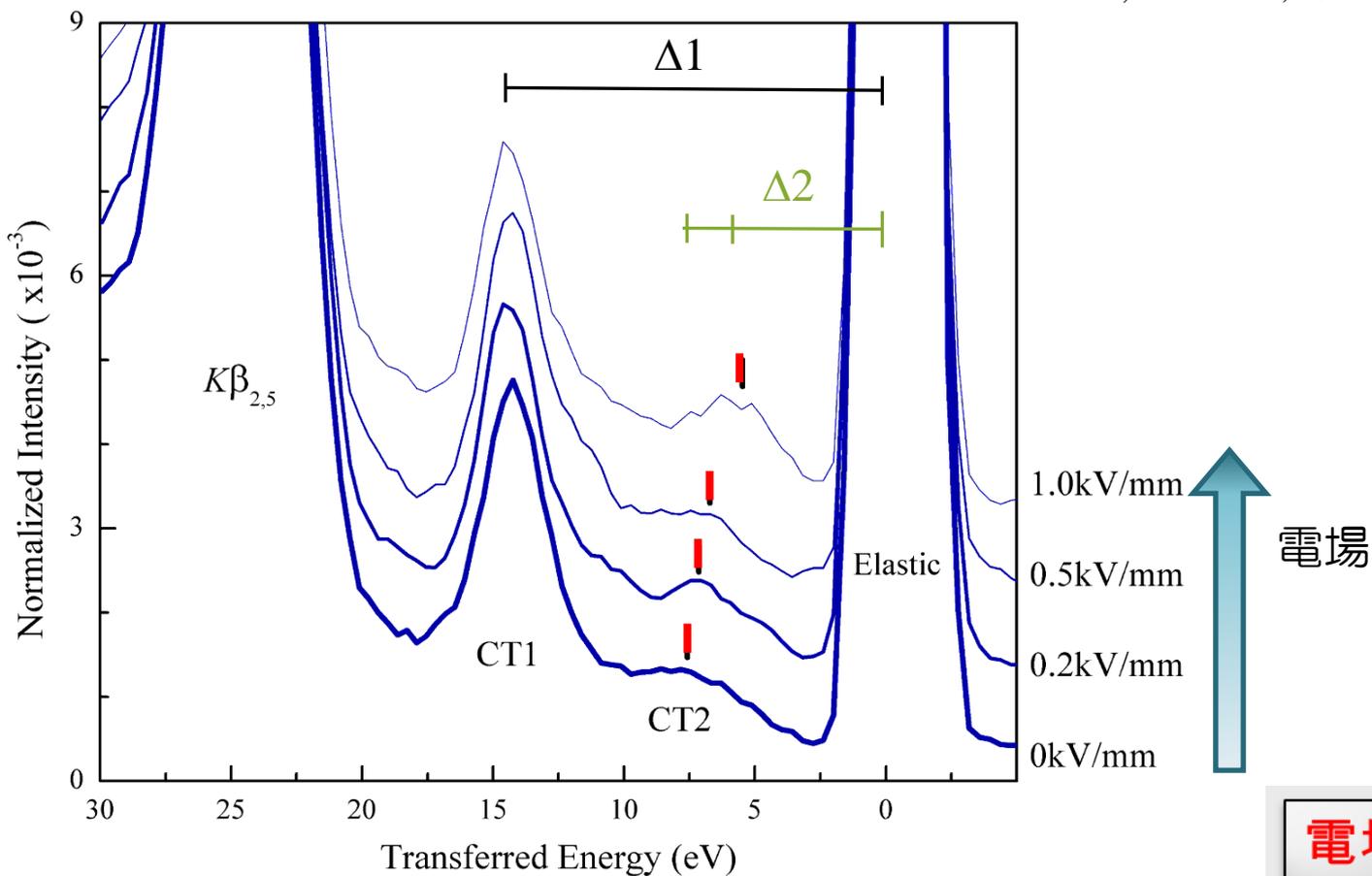
常誘電相

強誘電相



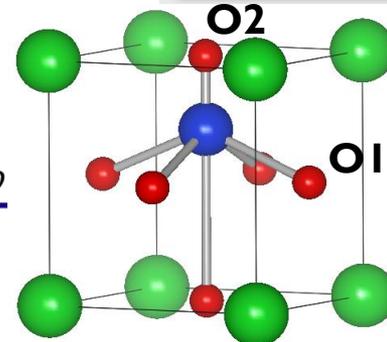
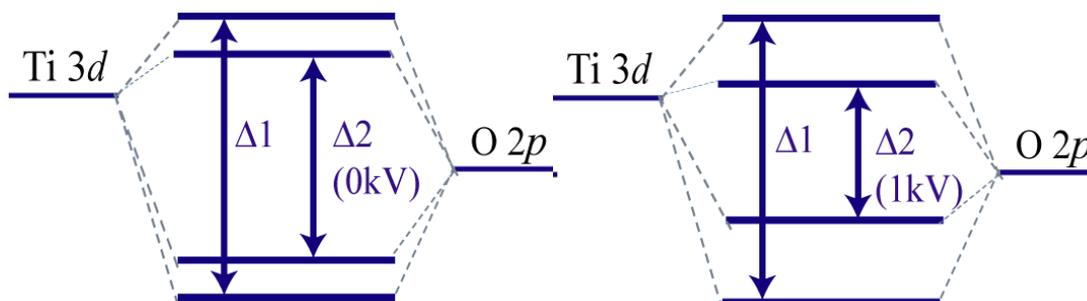
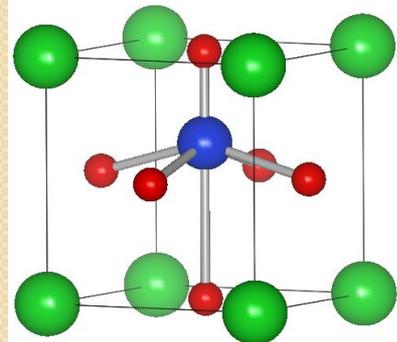
RXESスペクトル - 電場依存性 -

Y. Isohama, N.N. *et al*, *JJAP in press*

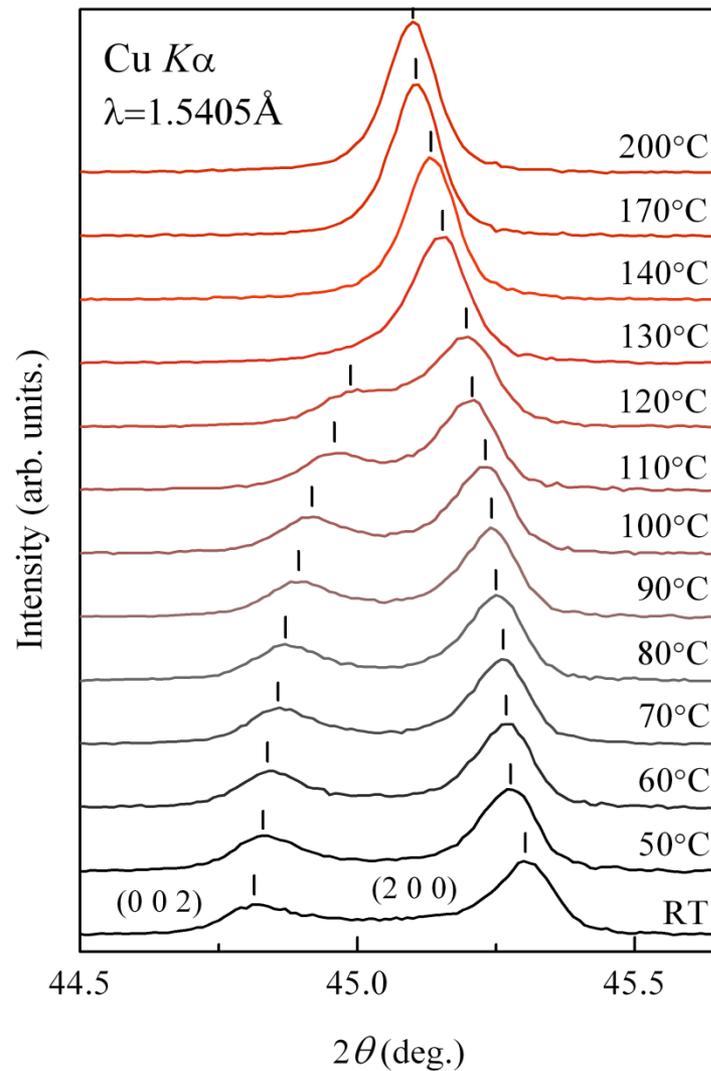
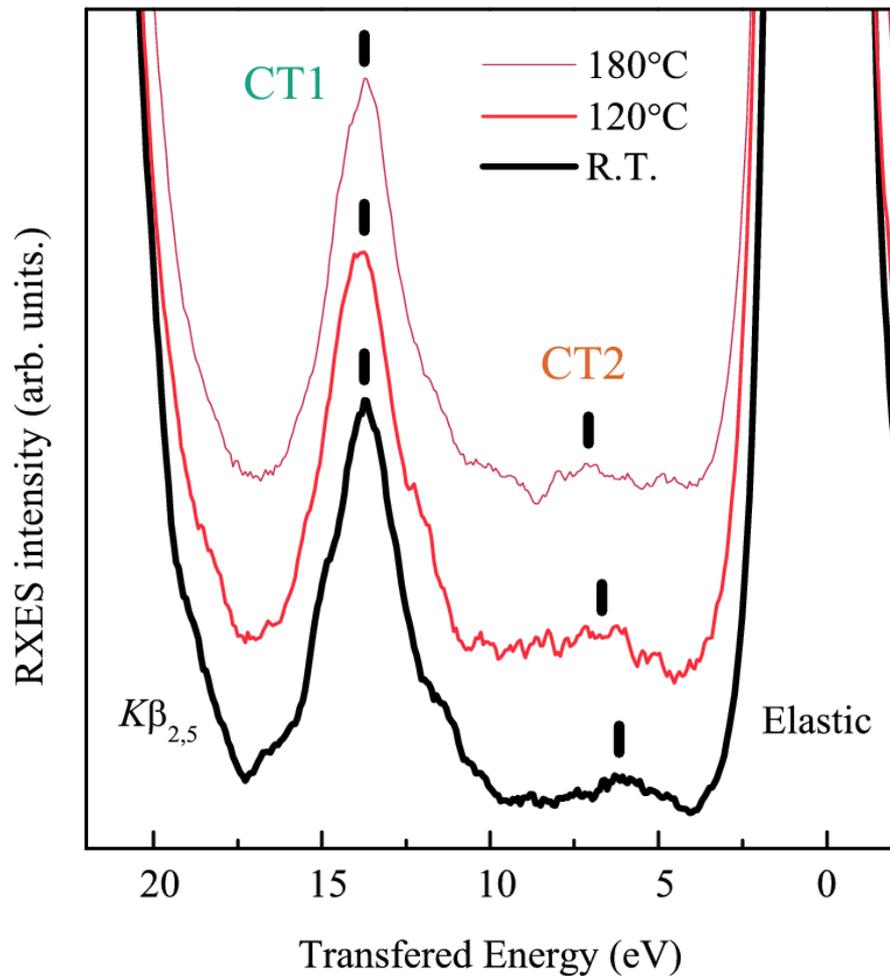


電場Off

電場On



RXESスペクトル - 温度依存性 -

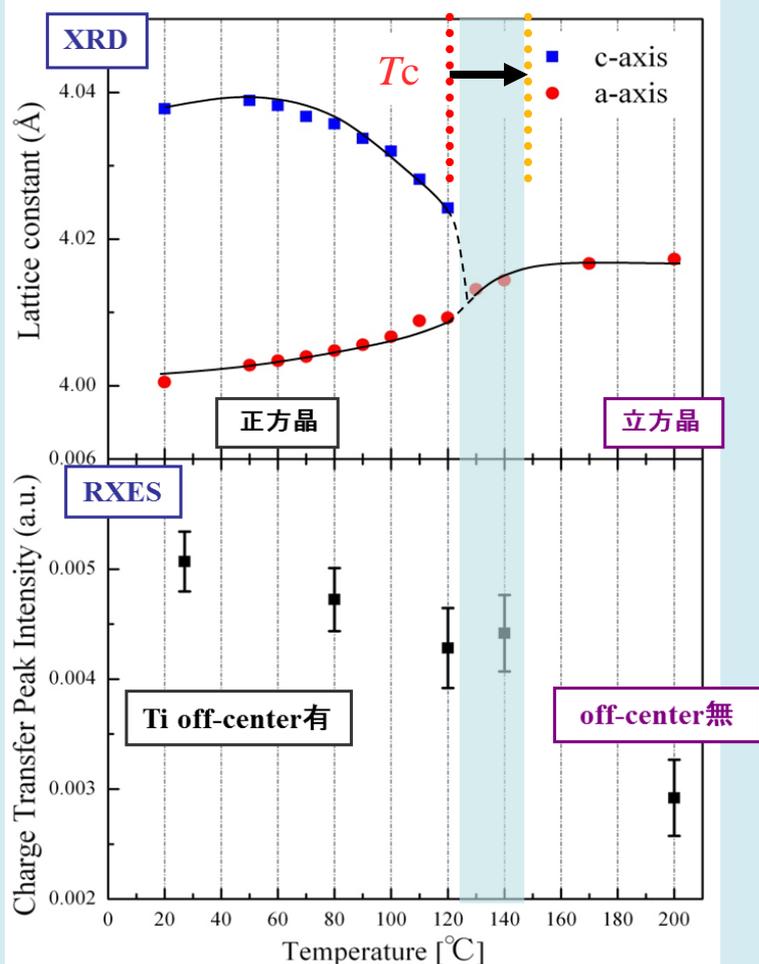


Y. Isohama, N. N. J. Elect. Spectro. Relat. Phenom. **184** (2011) 207.

共鳴X線発光分光法(RXES)

コヒーレントな
非弾性散乱成分

⇒Ti オフセンタリング



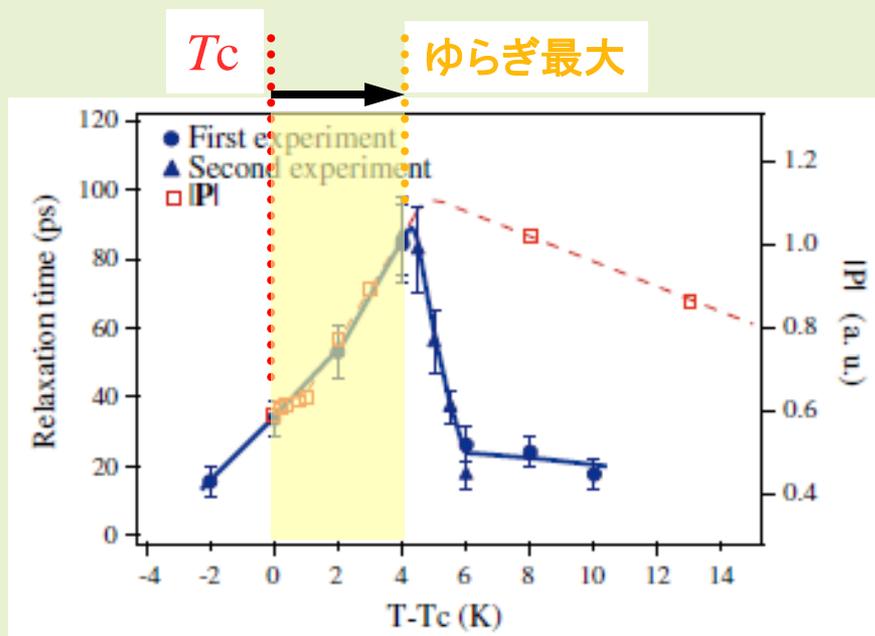
スペックル分光法

連続軟X線レーザーパルス

+

分極揺らぎ

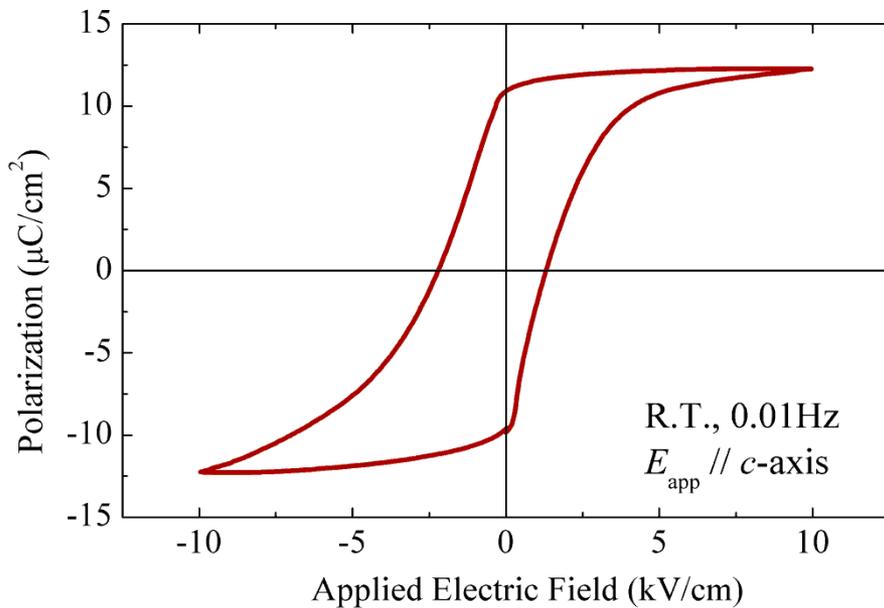
⇒干渉光測定



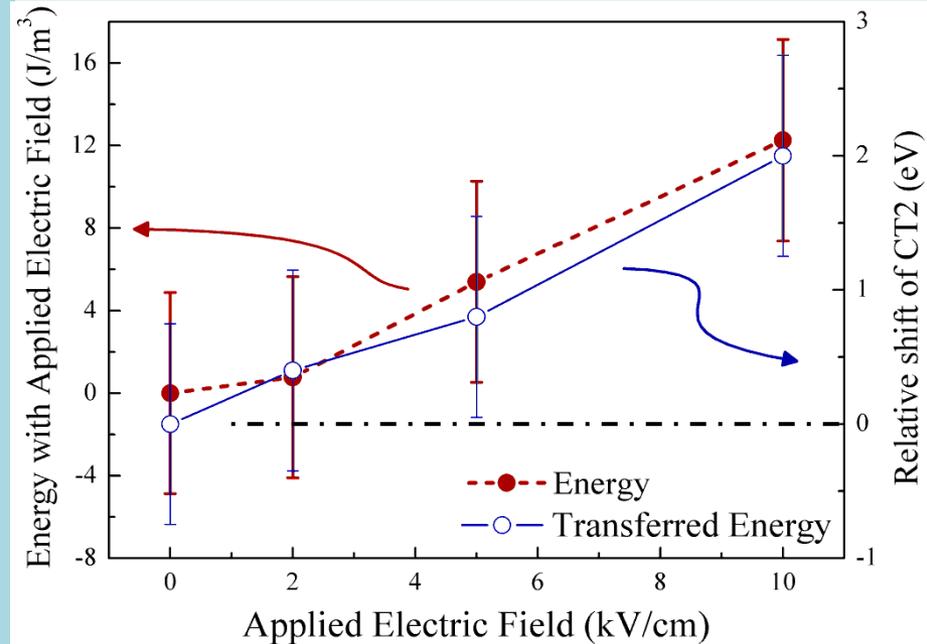
K. Namikawa et al., Phys. Rev. Lett. **103**, 197401 (2009)

電場依存性

P-Eヒステリシス測定



Energy(-P·E) と CT2シフトの比較

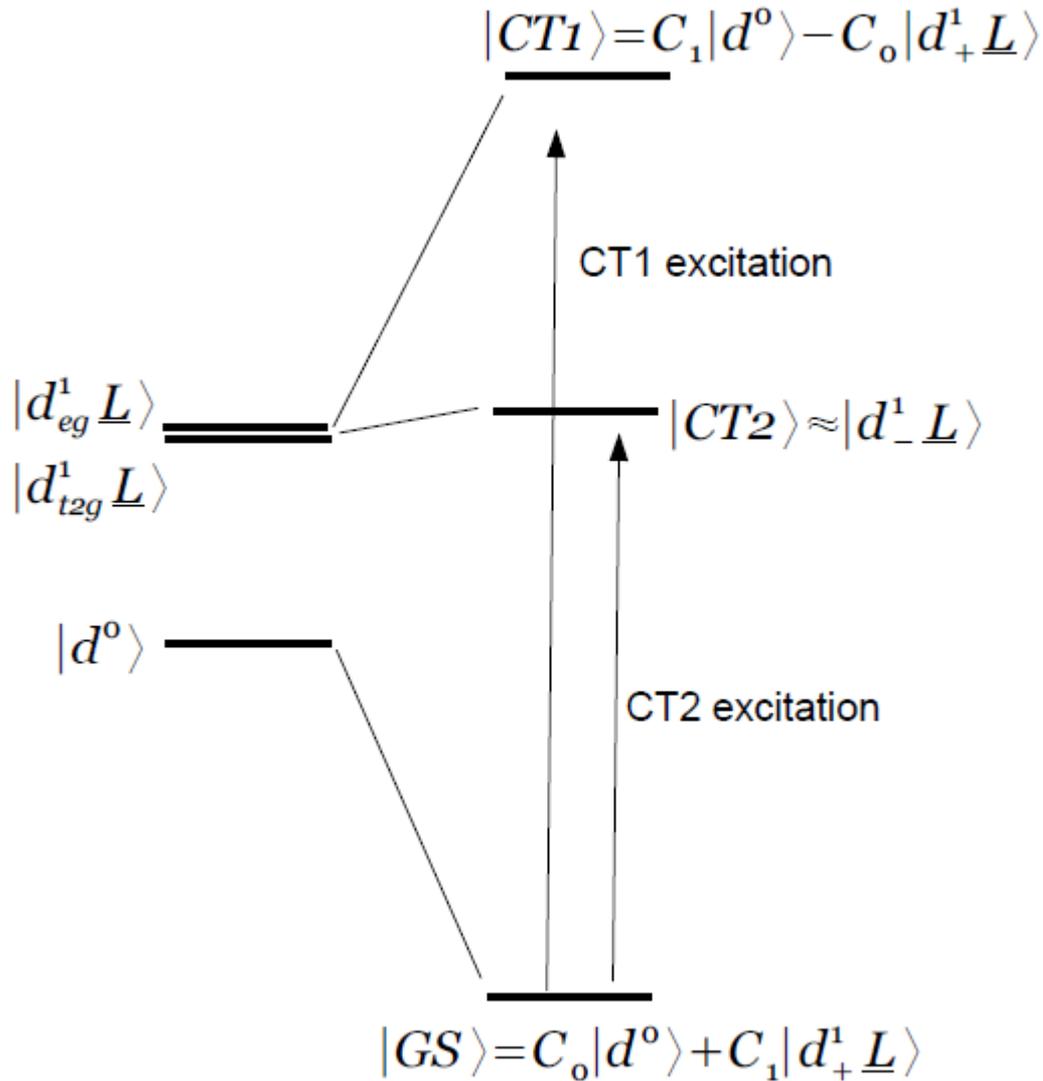


単位格子内のTiオフセンタリングが
 $BaTiO_3$ の誘電特性を決めている

球対称

立方対称

Thanks to K. Okada



d^0 と弱く混成する d^1L 状態

$$|d^1_{-L}\rangle \approx B|d^1_{t2g}L\rangle - A|d^1_{eg}L\rangle$$

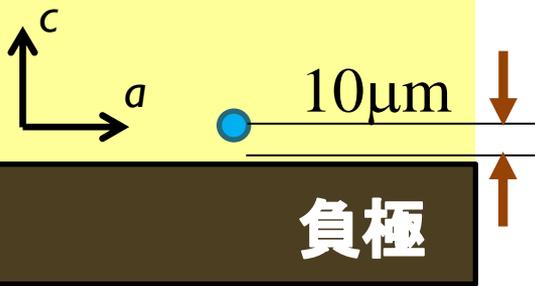
d^0 と強く混成する d^1L 状態

$$|d^1_{+L}\rangle \approx A|d^1_{t2g}L\rangle + B|d^1_{eg}L\rangle$$

X線ビームサイズ依存性 -入射位置変更-

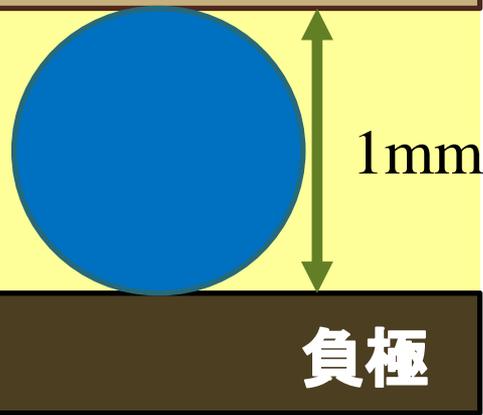
正極

Sample

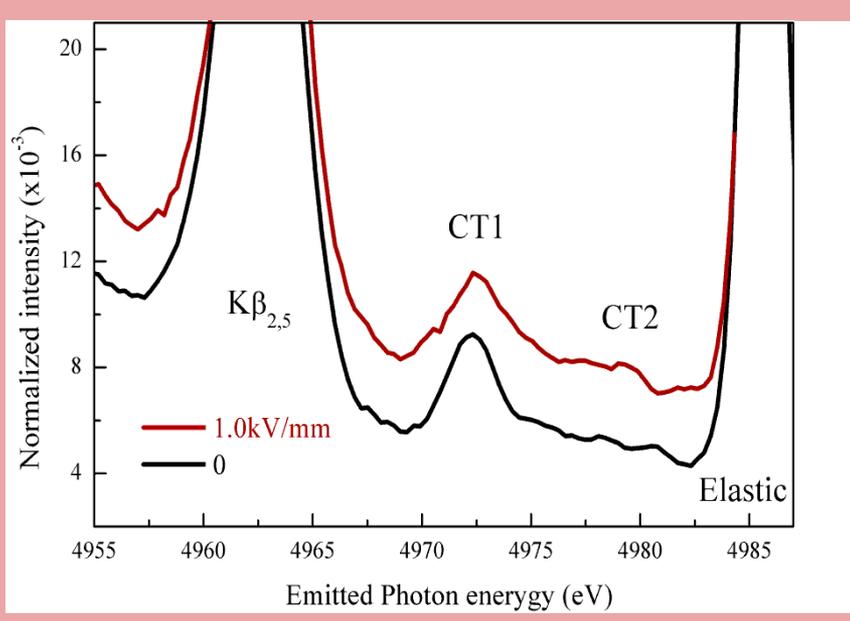
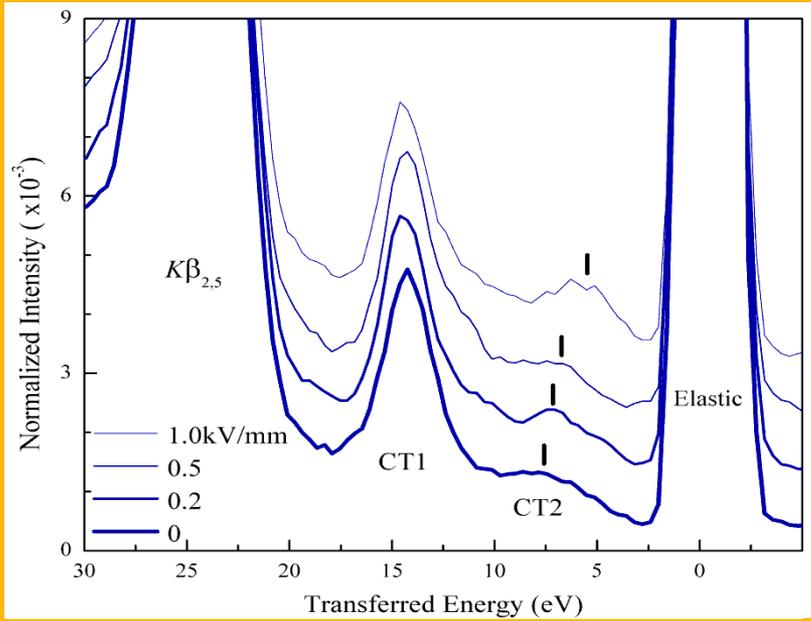


ビームサイズ
~ $\phi 10\mu\text{m}$

正極



ビームサイズ
~ $\phi 1\text{mm}$



負極近傍でTiオフセンタリングが生じている

Summary

- 電場印加下によるX線分光は、注目元素近傍の局所的な構造を反映する
 - ⇔ マクロな測定では、平均的な秩序を反映する
- 電極付近の歪みの影響
 - ⇔ 集光ビーム(10 μm 以下)が必要
- 実装デバイスでの活用