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1. Main Research Result

1) Mechanism of the size effect in barium titanate

Fine-grained barium titanate ceramics were fabricated by the two-steps intering method and the aerosol deposition method, and then the grain size effects were demonstrated. The dielectric and piezoelectric properties show a maximum at around 1 μm . The BaTiO₃ ceramics with an average grain size of 1 μm had high permittivity of 8,000 and high piezoelectric constant ($d_{33} = 460 \text{ pC/N}$). The maximum of dielectric and piezoelectric properties was explained by the effects of domain structure and grain-boundary structure

2) New piezoelectric fundamental equations

For describing piezoelectric responses under high-power driving, it is necessary to incorporate nonlinear responses and dissipation effects in the fundamental equation of piezoelectric effect. Many nonlinear and complex coefficients appearing in the equations make it difficult to solve those equations. We have found a way to simplify those equations by assuming one criterion where piezoelectric induced strain should be proportional to polarization without phase lag. The new fundamental equations based on this assumption were successfully describe the piezoelectric response under high-power driving.

3) Lead-free PTCR ceramics

As a lead-free PTCR (Positive Temperature Coefficient of Resistivity) thermistor material usable over 130 degree C, we have developed barium titanate - bismuth sodium titanate solid solution (BT-BNT) ceramics. Moreover, by introducing Ca and vacancies of sodium, the BT-BNT ceramics showed semiconducting behaviors. The electrical properties of the BT-BNT ceramics were comparable to those of the existing lead-contained PTCR ceramics. Based on these results, we are hoping for lead-free and rare-earth element-free PTCR ceramics.

2. List of Publication

- 1) Size Effect and Domain-Wall Contribution of Barium Titanate Ceramics, Takuya Hoshina, Youichi Kigoshi, Saki Hatta, Takashi Teranishi, Hiroaki Takeda, Takaaki Tsurumi, *Ferroelectrics*, 402, pp. 29-36, 2010.

- 2) 2. Effects of oxygen vacancies and grain sizes on the dielectric response, Youn-Kyu Choi, Takuya Hoshina, Hiroaki Takeda, Takashi Teranishi, Takaaki Tsurumi, *Applied Physics Letters*, Vol. 97, 212907 (3 pages), 2010.
- 3) 3. Effects of Ca and Zr additions and stoichiometry on the electrical properties of barium titanate-based ceramics, Youn Kyu CHOI, Takuya HOSHINA, Hiroaki TAKEDA, Takaaki TSURUMI, *Journal of the Ceramic Society of Japan*, Vol. 118, pp. 881-886, 2010.
- 4) Size Effect of Nanograined BaTiO₃ Ceramics Fabricated by Aerosol Deposition Method, Takuya Hoshina, Tsutomu Furuta, Youichi Kigoshi, Saki Hatta, Naohiro Horiuchi, Hiroaki Takeda, Takaaki Tsurumi, *Japanese Journal of Applied Physics*, Vol. 49, 09MC02 (5page), 2010.
- 5) Nonlinear Shear Responses of Lead Zirconate Titanate Piezoelectric Ceramics, Manabu Hagiwara, Takuya Hoshina, Hiroaki Takeda, Takaaki Tsurumi, *Japanese Journal of Applied Physics*, Vol. 49, p. 09MD04 (5 pages), 2010.
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- 7) Analysis on dipole polarization of BaTiO₃-based ferroelectric ceramics by Raman spectroscopy, Takashi TERANISHI, Naohiro HORIUCHI, Takuya HOSHINA, Hiroaki TAKEDA, Takaaki TSURUMI, *Journal of the Ceramic Society of Japan*, Vol. 118, pp. 679-682, 2010.
- 8) The influence of metal/perovskite-type oxide interfaces on tunability of thin film capacitors, Naohiro HORIUCHI, Takuya HOSHINA, Hiroaki TAKEDA, Takaaki TSURUMI, *Journal of the Ceramic Society of Japan*, Vol. 118, pp. 664-668, 2010.
- 9) Influence of Interface on Tunability in Barium Strontium Titanate, Naohiro Horiuchi, Takuya Hoshina, Hiroaki Takeda, Takaaki Tsurumi, *Ceramics Transactions*, Vol. 216, pp. 37-42, 2010.
- 10) Search for Piezoelectric Single Crystals for Sensing Applications at Elevated Temperatures, *CERAMICS JAPAN*, Vol. 45, pp. 474-478, 2010.
- 11) Effect of Metal-Dielectric Interfaces on Tunability in Barium Strontium Titanate Thin-film Capacitor, Naohiro Horiuchi, Takuya Hoshina, Hiroaki Takeda, Osamu Sakurai, Takaaki Tsurumi, *Key Engineering Materials*, Vol. 445, pp. 140-143, 2010.
- 12) Nonlinear shear response in (K,Na)NbO₃-based lead-free piezoelectric ceramics, Manabu Hagiwara, Seita Takahashi, Takuya Hoshina, Hiroaki Takeda, Osamu Sakurai, Takaaki Tsurumi, *Key Engineering Materials*, Vol. 445, pp. 47-50, 2010.

- 13) Dielectric Properties of Barium Titanate Ceramics with Nano-Sized Domain, Yoichi Kigoshi, Saki Hatta, Takashi Teranishi, Takuya Hoshina, Hiroaki Takeda, Osamu Sakurai, Takaaki Tsurumi, Key Engineering Materials, Vol. 445, pp. 27-30, 2010.
- 14) Evolution of Internal Stress and Influence on Dielectric Properties by Number of Dielectric Layers in MLCC, Satoshi Yokomizo, Takuya Hoshina, Hiroaki Takeda, Katsuya Taniguchi, Youichi Mizuno, Hirokazu Chazono, Osamu Sakurai, Takaaki Tsurumi, Key Engineering Materials, Vol. 445, pp. 31-34, 2010.
- 15) Growth and Piezoelectric Properties of Ferroelectric Bi_2WO_6 Mono-domain Crystals, Hiroaki Takeda, Joong Sang HAN, Masaya Nishida, Tadashi Shiosaki, Takuya Hoshina, Takaaki Tsurumi, Solid State Communications, Vol. 150, No. 17-18 pp. 836-839, 2010.
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- 17) Wide Band Dielectric Spectroscopy at Ferroelectric Phase Transition of BaTiO_3 Ceramics, Takashi Teranishi, Takuya Hoshina, Hiroaki Takeda, Takaaki Tsurumi, Jpn. J. Appl. Phys., Vol. 49, 041506 (4 pages), 2010.
- 18) Mechanism Underlying Stacking-Layer Effect of Dielectric Properties of Multilayer Ceramic Capacitors, Satoshi Yokomizo, Takuya Hoshina, Hiroaki Takeda, Katsuya Taniguchi, Youichi Mizuno, Hirokazu Chazono, Takaaki Tsurumi, Jpn. J. Appl. Phys., Vol. 49, 041505 (5 pages), 2010.

3. International and domestic conferences

International

- 1) Takaaki Tsurumi, Seita Takahashi, Manabu Hagiwara, Masayuki Yanagihashi, Takuya Hoshina, and Hiroaki Takeda, "Theory and Analysis of Transient Response to High Power Signals in Lead-based or Lead-free Piezoelectric Ceramics", CIMTEC2010, 6/6-11/2010, Montecatini Terme, Italy [Invited Talk].
- 2) Takaaki Tsurumi, Seita Takahashi, Keisuke Mihara, Masayuki Yanagihashi, Takuya Hoshina and Hiroaki Takeda, Piezoelectric Transient Response and Sensor/Harvester Applications, AMF-AMEC-2010, 6/28-30/2010, Jeju City, Korea [Invited Talk].
- 3) Takaaki Tsurumi, Seita Takahashi, Manabu Hagiwara, Takuya Hoshina, and Hiroaki Takeda, Analysis of nonlinear transient response with a new formulation of piezoelectric effect, China-Japan Symposium on Ferroelectric

- Materials and Their Applications, 10/14-17/2010, Kurobe, Toyama, Japan, [Invited Talk].
- 4) Takaaki Tsurumi, For Understanding Reliability Issue of MLCC, ICC3 (3rd International Congress on Ceramics), 11/14-18/2010, Osaka, Japan, [Invited Talk]
 - 5) Kotaro Takeda, Takuya Hoshina, Hiroaki Takeda and Takaaki Tsurumi, Correlation between the electro-optic effect and piezoelectric effect around resonance frequency, IMAPS/ACerS 6th CICMT, April 20, 2010, [Poster Presentation].
 - 6) Takuya Hoshina, Saki Hatta, Yoichi Kigoshi, Tsutomu Furuta, Hiroaki Takeda, and Takaaki Tsurumi, Size Effect on Dielectric and Piezoelectric Properties of BaTiO₃ Ceramics, IMAPS/ACerS 6th CICMT, April 20, 2010, Makuhari, Chiba, Japan, [Oral Presentation].
 - 7) Manabu Hagiwara, Seita Takahashi, Takuya Hoshina, Hiroaki Takeda and Takaaki Tsurumi, Nonlinear vibration analysis of piezoelectric ceramics based on the transient response, IMAPS/ACerS 6th CICMT, April 20, 2010 [Poster Presentation].
 - 8) Satoshi Yokomizo, Takuya Hoshina, Hiroaki Takeda, Katsuya Taniguchi, Youichi Mizuno, Hirokazu Chazono and Takaaki Tsurumi, Stacking-Layer Effect on Dielectric Properties of Multilayer Ceramic Capacitors, IMAPS/ACerS 6th CICMT, April 20, 2010, Makuhari, Chiba, Japan [Poster Presentation].
 - 9) Takuya Hoshina, Saki Hatta, Yoichi Kigoshi, Hiroaki Takeda and Takaaki Tsurumi, Size Effect and Domain-Wall Contribution of BaTiO₃ Ceramics, Electroceramics XII, 6/13-16/2010, Trondheim, Norway, [Oral Presentation].
 - 10) Manabu Hagiwara, Takuya Hoshina, Hiroaki Takeda and Takaaki Tsurumi, Measurement of Shear Strain near Mechanical Resonance in Piezoelectric Ceramics by Double-beam Laser Doppler Vibrometer, 6/20-24/2010, RCBJSF-10, Yokohama, Kanagawa, Japan [Oral Presentation].
 - 11) Kotaro Takeda, Takuya Hoshina, Hiroaki Takeda and Takaaki Tsurumi, Electro-Optic Effect around Piezoelectric Resonance Frequency, STAC-4, 6/21-23/2010, Yokohama, Kanagawa, Japan, [Oral Presentation].
 - 12) Naohiro Horiuchi, Takuya Hoshina, Hiroaki Takeda and Takaaki Tsurumi, Modification of the Schottky model for metal/Nb-doped SrTiO₃ Junction, AMF-AMEC-2010, 6/28-30/2010, Jeju City, Korea [Oral Presentation].
 - 13) Hiroaki Takeda, Takashi Tateishi, Naohiro Horiuchi, Takeshi Simada, Takuya

- Hoshina and Takaaki Tsurumi, Synthesis of (Bi_{1/2}Na_{1/2})-modified BaTiO₃ semiconducting ceramics in Air Atmosphere, AMF-AMEC-2010, Jeju City, Korea, 6/28-30/2010, [Oral Presentation].
- 14) Takaaki Tsurumi, Seita Takahashi, Manabu Hagiwara, Takuya Hoshina, and Hiroaki Takeda, Analysis of nonlinear transient response of piezoelectric resonators driven under high power condition, ISAF-ECAPD 2010, 8/9-12/2010, Edinburgh, Scotland [Oral Presentation]
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 - 18) Naohiro Horiuchi, Takuya Hoshina, Hiroaki Takeda, and Takaaki Tsurumi, Estimation of dielectric properties of metal - dielectric interface on strontium titanate, ISAF-ECAPD 2010, 8/9-12/2010, Edinburgh, Scotland [Oral Presentation]
 - 19) Naohiro Horiuchi, Takuya Hoshina, Hiroaki Takeda, and Takaaki Tsurumi, Estimation of interfacial capacitance between metal and perovskite-type oxide using modified Schottky model, WOE-17, 9/19-22/2010, Awaji, Hyogo, Japan [Poster Presentation]
 - 20) Hiroaki Takeda, Takashi Tateishi, Takeshi Shimada, Takuya Hoshina, and Takaaki Tsurumi, Influence of Sintering/Annealing Atmosphere on Electric Properties of (Bi_{1/2}A_{1/2})-Modified BaTiO₃ (A=Na, K) Semiconducting Ceramics, ISIAMOE-3, 10/17-20/2010 [Oral Presentation]
 - 21) Takuya Hoshina, Hiroaki Takeda, and Takaaki Tsurumi, Domain-wall Contribution to Dielectric and Piezoelectric Properties of Fine-grained BaTiO₃ Ceramics, ICC3 (3rd International Congress on Ceramics), 11/14-18/2010, Osaka, Japan [Oral Presentation].
 - 22) Hiroaki Takeda, Jun-ichi Yamaura, Takuya Hoshina, and Takaaki Tsurumi, Growth, Structure and Electrical Properties of Aluminum Substituted Langasite

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Domestics

- 1) 保科拓也, 古田 努, 八田彩希, 木越陽一, 武田博明, 鶴見敬章, エアロゾルデポジション法によるナノ粒子 BaTiO₃ セラミックスの作製とサイズ効果, 第 27 回強誘電体応用会議, 5/26-29/2010, 京都 [口頭発表].
- 2) 萩原 学, 高橋 星太, 保科 拓也, 武田 博明, 鶴見 敬章, PZT 系圧電セラミックスのシェアモードにおける非線形応答, 第 27 回強誘電体応用会議, 5/26-29/2010, 京都 [口頭発表].
- 3) 保科 拓也, 古田 努, 八田 彩希, 木越 陽一, 武田博明, 鶴見 敬章, AD 法による BaTiO₃ 系セラミックスの作製とサイズ効果, 2010 年秋季 第 71 回応用物理学会学術講演会, 9/14-17/2010, 長崎[口頭発表].
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- 7) 武田 博明、立石 貴志、島田 武司、保科 拓也、鶴見 敬章、BaTiO₃-(Bi_{1/2}A_{1/2})TiO₃(A=Na,K)系半導体セラミックスの作製と評価, 第 30 回エレクトロセラミックス研究討論会, 10/29-30/2010, 東京[口頭発表].
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- 9) 崔連圭, 保科拓也, 武田博明, 鶴見敬章, 広帯域周波数におけるチタン酸バリウム系セラミックスの酸素欠陥の効果, 第 30 回エレクトロセラミックス研究討論会, 10/29-30/2010, 東京[口頭発表].
- 10) 古田 努, 八田 彩希, 木越 陽一, 保科 拓也, 武田 博明, 鶴見 敬章, AD 法によるナノ粒子 BaTiO₃ 系セラミックスの作製とサイズ効果, 第 30 回エレクトロセラミックス研究討論会, 10/29-30/2010, 東京[ポスター発表].
- 11) 立石 貴志, 武田 博明, 保科 拓也, 鶴見 敬章, 大気中焼成による BaTiO₃-(Bi_{1/2}Na_{1/2})TiO₃ 系非鉛 PTC サーミスタの作製, 第 30 回エレクトロセラ

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- 13) 立石 貴志, 韓 重祥, 武田 博明, 保科 拓也, 鶴見敬章, CaO 添加による BaTiO₃-(Bi^{1/2}Na^{1/2})TiO₃ セラミックスの半導体化, 3/16-18/2011, 日本セラミックス協会 2011 年会 [口頭発表].
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- 15) 萩原 学, 保科 拓也, 武田 博明, 鶴見 敬章, 非線形性および損失を考慮した圧電基本式の実験的検証, 3/16-18/2011, 日本セラミックス協会 2011 年会 [口頭発表].
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- 19) 吉村知浩, 保科拓也, 武田博明, 鶴見敬章, 圧電セラミックスにおける反電界効果と振動解析, 3/16-18/2011, 日本セラミックス協会 2011 年会 [口頭発表].