DAWN OF VECTOR MATERIALS SCIENCE FOR MATERIALS INNOVATION

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Our recent study revealed that hydroxyapatite (HA) has an unreported and invaluable biological effects;¹⁻⁸⁾ bonelike crystal growth was controlled on polarized HA in simulated body fluid (SBF),¹⁻³⁾ and cells^{4, 5)} and bacteria⁶⁾ showed different biological behavior such as adhesion and proliferation characteristics on polarized HA from unpolarized one. Based on these findings, we identified "electrovector" effects of polarized HA.⁹⁾ The word "vector" is employed as the upper concept for "electrovector" in order to search for new groups of "vector materials." The term "vector" is commonly used in mathematics and biology, and has originally the definition as:

(1)(a) *a quantity that has magnitude, direction, and sense.* (b) *an organism that transmits a pathogen.*

(2) *to guide (as an airplane, its pilot, or a missile) in flight by means of a radioed vector.*

On the basis of the usage, we define vector, vector materials, and vector effects for biomedical materials application as:

vector (*n*, *vt*); *to manipulate the constituents of living body and environmental system such as non-alive substances of ions, proteins sugars, and alive cells and bacteria, tissues and organs bi biocompatible materials themselves.*

vector material; *a material which has an ability to vector.*

vector effect; *an effect which a vector material brings forth.*

The concept of vector is reasonably extended to manipulation of a local target space by a material or an external field (Fig.1). The latter is referred to as vector fields. Vector materials science is therefore defined as the study of principles of vector, vector materials, and processing and related techniques for vector materials by vector fields.

A demonstrative example of a vector material can be taken from biomedical applications. In a biological condition surrounded with water, typical electrolytic substance, and lots of ionic groups including proteins and cells local electrostatic influence is sometimes desirable. The application of external fields is limited in such system, because of some hazardous side effects of damaging cells or tissues. Alternatively, electrets, which irradiate electrostatic working force independently, can be effective for such system. Under a certain circumstance of a quasi-closed system such as human body, use of an external field is limited because of side effects or set-up problems of continuous power supply and electrodes. For such situation, independently workable substances such as magnets are expected to have great benefits, because they can bring effects only to a given local spot. Such materials are expected to have useful effects in some applications of environmental devices as well as biomedical ones.

Polarized HA¹⁰⁾ is thus a member of vector materials. Ceramic magnets and electrets are therefore typical vector materials after the definition. A radioactive material is another candidate of vector material because they can individually irradiate a force to its surrounding. Radioactive ceramics incorporated in glass beads have already been applied to medical applications for cancer therapy. These materials are classified as radioactive vector ceramics. 45S5-type bio-glass and β -tricalcium phosphate are dissolved in a body and release chemical constituents or artificial chemicals, resulting in good bone conductivity. These materials fall to chemivector materials

Fig.1 Definition of vector field and materials.

Table 1. Summary of vector effects.

Effect	Force
Single	
Electrovectro	Electrostatic
Magnetovectro	Magnetic
Chemicovectro	Dissolution
Optovectro	Luminescence
Radioactivevectro	Radioactive ray
Mechanovectro	Strain
Complex	
Chemico-electrovectro	Electrostatic/dissolution

We summarize these materials and effects as Table 1, giving the classification of the family of vectors ceramics on the basis of the mechanisms to drive the effects. The concept of vector ceramics is expected to open a new way for innovation or creation of ceramic science. The concept has already been expanded to some extent ceramic processing¹¹⁾ and an application of vector effects has been put in use.¹²⁾ Nakahira *et al.* are introducing “magnetovector field effect” for using high magnetic field. Kasuga *et al.* successfully prepared fast proton conductors on the basis of the chemicovector concept using hydration of calcium phosphate glass.

Combination of several vector effects may amplify an effect. To date, one example has been identified as the mixed vector material, *i.e.*, polarized 45S5-type bio-glass as chemico-electrovectro ceramic.¹³⁻¹⁵⁾ Although the other vector materials such as mechanovector or optovector materials are under development, a variety of developed functional materials are reasonably expected to have excellent vector effects for biomedical use.

REFERENCES

1. K. Yamashita, N. Oikawa, T. Umegaki, *Chem. Mater.*, **8**, 2697 (1996).
2. H. Takeda, Y. Seki, S. Nakamura, K. Yamashita, *J. Mater. Chem.*, **12**, 2490 (2002).
3. M. Ueshima, S. Nakamura, M. Ohgaki, K. Yamashita, *Solid State Ionics*, **151**, 29 (2002).
4. T. Kobayashi, S. Nakamura, K. Yamashita, *J. Biomed. Mater. Res.*, **57**, 477 (2001).
5. M. Ohgaki, T. Kizuki, M. Katsura, K. Yamashita, *J. Biomed. Mater. Res.*, **57**, 366 (2001).
6. M. Ueshima, S. Tanaka, S. Nakamura, M. Ohgaki, K. Yamashita, *J. Biomed. Mater. Res.*, **60**, 578 (2002).
7. S. Nakamura, T. Kobayashi, K. Yamashita, *J. Biomed Mater. Res.*, **61**, 593 (2002).
8. S. Nakamura, T. Kobayashi, K. Yamashita, *J. Biomed. Mater. Res.* **68A**, 90 (2004).
9. K. Yamashita, *Phosphorus Sulfur*, **177**, 1889 (2002).
10. S. Nakamura, H. Takeda, K. Yamashita, *J. Appl. Phys.*, **89**, 5386 (2001).
11. A. Nakahira, S. Konishi, H. Yasuda, I. Ohnaka, *J. Ceram. Soc. Japan, Suppl.*, **112**, S845 (2004).
12. T. Kasuga, M. Kawase, Y. Daiko, M. Nogami, *J. Ceram. Soc. Japan, Suppl.*, **112**, S800 (2004).
13. A. Obata, S. Nakamura, Y. Moriyoshi, K. Yamashita, *J. Biomed. Mater. Res.*, **67A**, 413 (2003).
14. A. Obata, S. Nakamura, K. Yamashita, *Biomaterials*, **25**, 5163 (2004).
15. A. Obata, S. Nakamura, Y. Sekijima, K. Yamashita, *J. Ceram. Soc. Japan, Suppl.*, **112**, S822 (2004).