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High throughput combinatorial materials exploration for advanced magneto-electronics

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1. Introduction

Electron charge plays central role in modern electronics, however, recent development in solid state physics has unveiled importance of another degree of electron, spin, in both magnetic and nonmagnetic materials. For practical applications, magnetic materials are regarded as a strong candidate for advanced electronic materials like beyond-CMOS technology. For example, metallic superlattice and tunneling junction show giant magnetoresistance and colossal tunneling magnetoresistance, respectively, and transition metal oxides by themselves show colossal magnetoresistance. Those phenomena are caused by interplay between the charge and spin degrees of freedom.

From aspect of exploration of such magnetic materials, various material parameters such as dopant elements have to be surveyed. To this end, combinatorial methodology is a powerful tool [1]. This method enables to synthesize and characterize a large number of compounds efficiently. Such experimental manner is advantageous for the discovery of new compounds as well as the systematic data acquisition. Here, the author describes combinatorial techniques and their applications to magnetic materials, particularly transition metal oxides.

2. Combinatorial methodology

Synthesis

The most prevailing method for synthesis of oxides is physical vapor deposition such as sputtering and pulsed laser deposition methods [1]. The latter has been extensively used for high quality growth of various oxide thin films, thus high quality growth of combinatorial thin films is in principle possible, by developing standard pulsed laser deposition method.

Figure 1 shows various synthesis techniques derived from pulsed laser deposition method. Temperature gradient method utilizes high power infrared laser for heating a customized substrate holder (Fig. 1(a)). By focusing the laser spot, growth temperature linearly changes with the position, so that it is possible to grow the film at different temperatures for one-run deposition. This method drastically reduces a cost for optimization of growth temperature. Composition-spread method utilizes computer-controlled moving mask, shutter, and target holders (Fig. 1(b)). This method enables to grow a large number of compositions on one-centimeter-square substrate. By designing the mask pattern, it is possible to synthesize discrete-phase-spread film and parallel superlattices on the substrate (Figs. 1(c) and (d)).

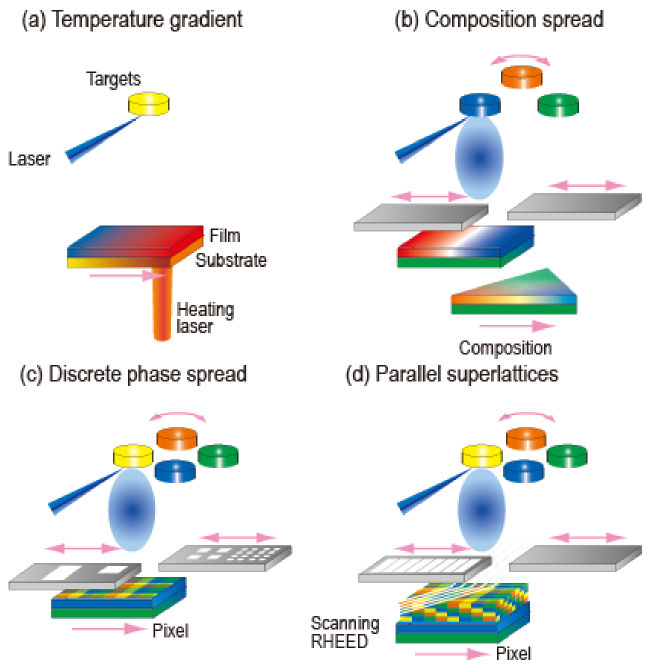

Fig. 1 Schematic illustrations of (a) temperature-gradient method, (b) composition-spread method, (c) discrete-phase-spread method, (d) parallel superlattices synthesis with use of scanning reflective high energy electron diffraction (RHEED), derived from pulsed laser deposition method.

Magnetic characterizations

For magnetic characterization, it is difficult to utilize conventional magnetometer since it has no spatial resolution required for characterizations of combinatorial thin films. One useful method for the magnetic characterization is scanning probe microscopy (Fig. 2) such as scanning superconducting quantum interference device microscope and magnetic force microscope that can observe magnetic domain structure even in absence of external magnetic field. The alternative method is magneto-optical measurement that can detect millimeter-sized magnetism by optical means (Fig. 2). The scanning superconducting quantum interference device microscope is quite sensitive to magnetic field, thus it is powerful to detect stray magnetic field from new magnetic phase in spite of less availability. On the other hand, the magneto-optical measurement is readily available for evaluation of magnetic properties such as magnetization and coercive force of magneto-optically active materials.

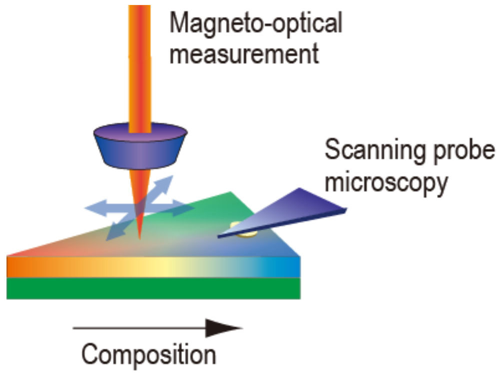

Fig. 2 Schematic illustrations of scanning probe microscopy and magneto-optical measurement for magnetic characterization.

Electric characterizations

Electric measurements are indispensable to characterize magneto-electric materials, since the magneto-electric coupling ultimately results in electric detection and control of magnetic properties. The most conservative method is electric measurements of electrically separated samples in sequence at the expense of time-consuming cost. The more efficient method is development of hardware such as multiterminal electric probe [2] and customized substrate embedded with electrical connections [3].

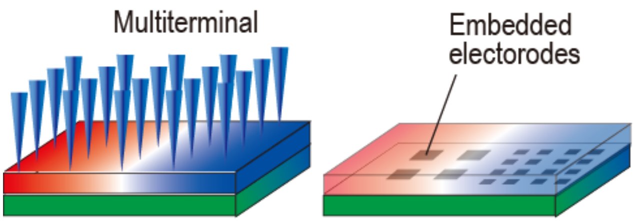

Fig. 3 Schematic illustrations of electric measurements. Multiterminal method (left) and use of customized substrate embedded with electrical connections (right).

3. Conclusions

By using the combinatorial methodology, various magnetic materials such as magnetoresistive manganese oxides, spinel-type cobalt ferrites, and spintronic magnetic oxide semiconductors can be investigated in quite efficient manner. Fast screening of various properties is easily possible. A room temperature ferromagnetic semiconductor discovered with this combinatorial approach are developed toward transparent semiconductor spintronics [4,5]. Such development will be also shown.

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