Basic Technology Subjects

Materials Science Research Laboratory

Brief Overview

The mission of the Materials Science Research Laboratory is to contribute to reliable electric power supply and the creation of a low-carbon society through fundamental material research for field applications to electric power plants, renewable energy utilization, and new materials development for energy conservation.

Achievements by Research Theme

Structural Materials

We will contribute to the reliable and stable operation of thermal and nuclear power plants through research activities such as fundamental data accumulation of high temperature materials strength and corrosion behavior, development of lifetime evaluation methods for aged structural components and the development of non-destructive inspection technologies.

- Creep strain equations have been developed in collaboration with the Electric Power Research Institute (EPRI), for Grade 92 steel, which is being progressively employed in newly built USC plants as a modified version of 9Cr steels. These equations provided a way to estimate progress of creep deformation as well as accompanying damage accurately, only from the creep rupture data of each product[1].
- The effect of periodical gas composition fluctuation in atmosphere on the sulfidation of water-wall tube made of low-alloy steels (STBA20, STBA22 and STBA24) has been clarified through corrosion tests conducted by periodically switching gas feed conditions between sulfidizing and oxidizing atmosphere. A technique for quickly and non-destructively identifying sulfidized areas on water-wall tubes has been applied to some commercial boilers, and sulfidized areas and tube thinning areas have been detected in some thermal power plants (Fig. 1).

Advanced Functional Materials

We will develop new functional materials (such as high-temperature superconductors, organic semiconductors, and ionic liquids) and will extend their application fields by utilizing various sophisticated techniques of growing and characterizing the materials.

- We improved growth techniques of iron-chalcogenide superconductors, and succeeded in raising superconducting critical temperature from 8 K to 12 K in FeSe thin films, and 14.2 K to 19 K in $FeSe_{0.5}Te_{0.5}$ thin films[2]. These films also exhibited extremely high critical current density at a high-magnetic field, and are anticipated as one of the candidates of practical superconducting coated conductor materials.
- We developed a new kind of organic device called a light-emitting electrochemical cell, and succeeded in preparing three basic colors, red, green, and blue (RGB), that are indispensable for display applications. These devices also exhibited a refreshing effect by current alternation, which is one of the key technologies for long-term stability

High Performance SiC Semiconductor for Power Electronics

To realize next generation low-loss power conversion equipment, we will establish a high-quality silicon carbide (SiC) crystal growth technology which enables the fabrication of low-loss, high-voltage, SiC power devices able to handle large currents.

- We developed production technology for high-quality SiC crystal films (epilayers) applicable to high-voltage and low-loss power semiconductor devices by engaging in collaborative development with several companies and established a crystal growth technique which obtained stable low defect density and highly uniform SiC crystal film with a high production rate on a 6-inch diameter substrate.
- We attempted to increase the growth rates in SiC bulk crystals and achieved crystal growth of SiC at a rate of 2.1 mm/h, which largely exceeded that of the conventional growth technique (sublimation method), maintaining quality equivalent to the high-quality seed crystal[3].
- Towards the reduction of defects (dislocations) in SiC crystals, we accomplished three-dimensional imaging of dislocations in SiC using a non-destructive optical method (two-photon-excited photoluminescence*1) (Fig. 2)[4] and by controlling the propagation direction of the dislocations by growing a SiC layer on a patterned substrate[5].

Materials Science Research Fundamentals

By integrating our fundamental technologies on computer simulations and advanced material analysis, we will promote

Achievements by Research Theme

the development of a multi-scale material strength evaluation method, and the development of metallographic change for high chromium steels.

- The nano-structure of high chromium steels was analyzed using a UV laser atom probe*2, and the distributions of nano-scale precipitates and trace carbon were disclosed.
- A finite element analysis code for crystal plasticity was developed. The increase of plastic strain due to creep deformation could be reproduced by simulating the collapse of lath structures*3, which was a typical degradation mechanism for high chromium steels.

*1 Luminescence created by electrons excited to a level double that of the incident beam energy by the simultaneous absorption of two photons.
*2 The pulsed UV laser enables atom probe measurement of high chromium steels, as it achieves efficient field evaporation.
*3 High density of dislocation in lath martensitic structure is one of the causes of high creep strength in high chromium steels. The collapse of the lath structures (decrease of dislocation density) is considered to cause the decrease in creep strength.

[1] H. Shigeyama et al., Proc. the 52nd Symposium on Strength of Materials at High Temperature, Hakodate, 2014.
[2] I. Tsukada et al., Jpn. J. Appl. Phys. 54, 043102, 2015.
[3] N. Hoshino et al., Appl. Phys. Express 7, 065502, 2014.
[4] R. Tanuma et al., Appl. Phys. Express 7, 121303, 2014.
[5] H. Tsuchida et al., J. Cryst. Growth 402, 260, 2014.

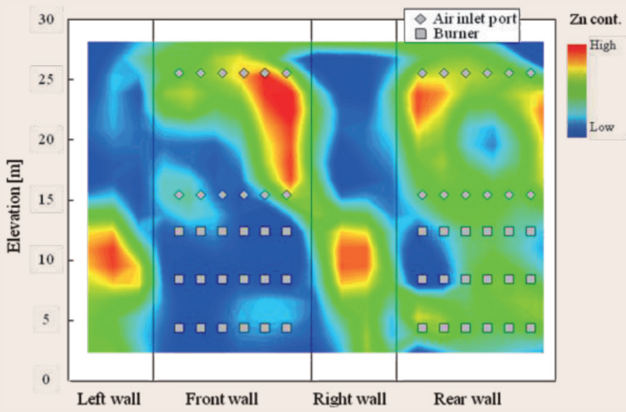

Fig. 1: Distribution of Zn content in the ash on the water-wall tube surface in a coal-fired boiler

Severe sulfidation occurs in areas where coal ash deposits contain a comparatively high Zn content. Sulfidation in the entire region of commercial boilers can be easily detected without descaling and within several hours by the use of a handheld X-ray fluorescence analyzer.

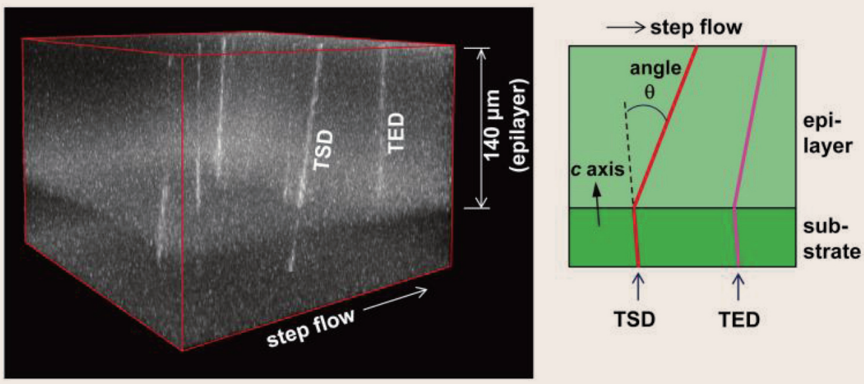

Fig. 2: Three-dimensional image of threading screw dislocations (TSDs) and threading edge dislocations (TEDs) in the SiC epilayer obtained by two-photon-excited photoluminescence

Propagation of threading and edge dislocations making an inclination angle throughout a SiC epilayer is visualized in three dimensions.