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RADIATION DEFECTS IN FUNCTIONAL MATERIALS FOR NUCLEAR APPLICATION

Fusion reactors attract great interest as a potential source of environmentally clean energy. The radiation-resistant oxide insulators (MgO, Al2O3, SiO2, MgAl2O4, Gd3Ga5O12, BeO etc), as well as MgF2 and diamond are of great importance for optical windows, diagnostic measurements, and other fusion reactor applications. Functional materials properties are defined by radiation defects therein. From a practical point of view, it is very important to understand and predict their properties and functional characteristics in a very wide range of radiation doses under various radiation particle, including whole range of neutrons, protons, swift heavy and light ions as well as gamma radiation. It is quite obvious that accurate and objective predictions are especially important, since they are made for conditions that are difficult to experimentally verify and implement both because of the high cost and the inaccessibility of the corresponding reactors.
In a series of joint works by ISSP UL (Latvia), UT (Estonia) and KIT (Germany), radiation damage of some promising functional materials (Al2O3, MgAl2O4, SiO2, diamond and few more) from the priority list of the EUROfusion consortium was studied under neutron, proton, heavy ion [1-8].
The optical and dielectric, vibrational and magnetic properties of numerous crystalline and ceramic materials were carefully studied. Based on this study, we developed new theoretical methods able to evaluate and predict some important properties of these materials as well as their radiation damage evolution under extreme reactor conditions.
In this series of papers [1-8], the radiation damage evolution and its subsequent thermal annealing were treated as the bimolecular process with equal concentrations of the complementary point defects, such as anion vacancies of different charge states and appropriate interstitial defect. Knowledge of the mobility of produced radiation defects, the effect of incident radiation in the conditions of progressive radiation-induced material disordering are absolutely necessary for detailed description of radiation damage.
The appropriate migration energies were obtained experimentally or derived from available thermal annealing kinetics for differently irradiated materials. In some cases, the results obtained are compared with ab initio calculations of interstitial migration [1,6]. Special attention was paid to:
(1) dose effects on point defect annealing [1-5,7];
(2) detailed comparison of diffusion-controlled point defect thermal annealing in gamma, proton, neutron, electron and heavy-ion irradiated oxides and halides [1-5,7,8];
(3) the point defect annealing and metal colloid formation in thermochemically reduced oxides and oxides and halides under irradiation [1,7].
It is demonstrated that both transparent ceramics and single crystals, as well as different types of irradiation show qualitatively similar kinetics, but the effective migration energy and pre-exponent are strongly correlated. Such correlation is discussed in terms of the so-called Meyer-Neldel rule known in chemical kinetics of condensed matter [2], but observed for the first time in irradiated materials.
Finally, we report our recent results of stepwise thermal annealing of radiation-induced optical absorption in ion-irradiated CVD diamonds, where the simultaneous decay of complementary pairs of Frenkel defects (absorption bands at 2 and 4 eV) was found.
This study allows us to prognosticate and control radiation and optical properties of advanced functional materials for fusion applications.

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Section

Energy and materials science (Section 2)

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