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Rare Earth Permanent-Magnet Alloys' High Temperature Phase Transformation

In Situ and Dynamic Observation and Its Application in Material Design

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Foreword

Material is one of the three primary mainstenance of the modern civilization and new material is taken for the bases and precursor of new technology revolution. Extent of production, development and application of the permanent-magnetic material is one of the indicatings for the extend of development of the contemporary national economy. Average family use of the permanent-magnetic material is also regarded as a measure of the live standard of the modern countries.

In resent years the requirement of the world for the rare earth permanent-magnet material has grown by 30% annually, synchronously, the kinds of this material have been developed, quality of products of the material has been improved and variety of the products has been extended continually in despite of impact the financial crisis on economies of many countries. Scientific and technological researches and industrialization of the rare earth permanent-magnet materials in China have achieved joyful result. "Rare Earth Permanent-Magnet Alloys' High Temperature Phase Transformation: In Situ and Dynamic Observation and Its Application in Material Design" is a monograph written by Professor Shuming Pan, the General Research Institute for Nonferrous Metals, China. This book includes study results of the author for more than thirty years, and researches thermodynamics, kinetics and metallography of phase transformation related to the rare earth permanent-magnet alloys by the current solid phase transformation theory, especially driving force and resistant of phase transformation, homogeneous and inhomogeneous nucleation, the law of growth up of new phase, internal energy change between phase transformation, the free enthalpy of phase transformation, diffusion type continual phase transformation, etc. This book analyzes and discusses in depth magnetism of the first and the second generations rare earth permanent-magnet materials at 1.5K, introduces magnetism and its variation curves at –196℃ to 200℃, and introduces the law of phase transformation of the third generation rare earth permanent-magnet alloys at temperature from room temperature to 960℃ and experimental video record of the whole process of high temperature phase transformation. The book also discusses manufacturing technique, principle and composition of the rare earth permanent-magnet alloys, and

the effect of above factors and on microstructure and performance of the alloy. These experiment results may be called very precious and provides important reference for study, education, production and development of the permanent-magnet materials.

China is a country with plenty rare earth resource. To transform advantage of resource into higher economic benefit it needs more efforts of scientific technical staffs to promote continual development. For this purpose Professor Shuming Pan has made his contribution. I, hereby, wish him to obtain new achievement.

I congratulate the publish of this book.

April, 2010 Changxu Shi

Preface

Rare earth permanent-magnet alloys are new function materials developed in the 1960s. With the progress of science and technology, human has stridden forward the information age. Permanent-magnet alloys have been rapidly developed. Level of their applications has been one of the measures of people's life standards. The permanent-magnet alloys have been one of substantial bases for developing modern science and technology, such as computer, space and aviation, communications, metallurgy, chemical engineering and medical protection. Meanwhile, the rare earth permanent-magnet alloy has developed gradually from one of common members to dominant role in the family of permanent-magnet alloys. By 2010, it has occupied 55% of the permanent-magnet market. The twenty first century will be the age of great developments for the rare earth permanent-magnet alloys.

The author has studied the first generation of rare earth permanent-magnet alloys, $SmCo_5$, the second generation $Sm(Co, Cu, Fe, Zr)_{7.4}$ with high coercivity, and the third generation NdFeB series for more than twenty years. The studies include the law of phase transition from room temperature to 1000℃ for the rare earth permanent-magnet alloys, based on modern theory of solid phase transition. The author studied the driving force and resistant force of the phase transition, homogeneous and non-homogeneous nucleation, growth of new phase, nucleation ratio, free enthalpy, and diffusively continuous phase transition. The phase transition is important in materials science. Theory of solid phase transition is a gold key to open the door of materials science: "you would not understand metal materials without understanding the solid phase transition." It is expected that the book is of benefit to science researchers, producers, teachers and students working in rare earth permanent-magnet and other materials, magnetism, metallurgy and chemical engineering. Therefore, the objectives of the book are to investigate the phase transition of rare earth permanent-magnet alloys from room temperature to high temperature and its correlation with magnetic properties and to summarize the key technology of fabrication, in order to improve the properties of the alloys, create new materials and new process, and accelerate development of the alloys.

Parts of achievements about high temperature phase transition in the book have

been reported on Chinese Science (in English and Chinese), Journal of Physics (in Chinese), Journal of Non-ferrous Metals (in Chinese), Journal of Metal (in Chinese), Journal of Rare Earth (in Chinese), and international journals: Journal of Applied Physics, IEEE Transaction Magnetics, and Journal of Magnetism and Magnetic Materials. The results have attracted much attention of scholars in the international conferences. Professor K. J. Strnant, pioneer in the first generation rare earth permanent-magnet alloys, attended an international conference hold in China in 1983. We showed him the image-recording of high temperature phase transition for rare earth permanent-magnet alloys. When he saw the Sm_2Co_7 phase separated from matrix phase and the process of new phase transition in the image-recording, Professor Strnant was excited and praised that the achievement was the advanced level in the world. He said: "I proposed that the coercivity of $SmCo_5$ is determined by the pinning of thin layer Sm_2Co_7 at crystal boundary. However, Sm_2Co_7 was not observed directly. Now we see it in China. You should report on this new discovery in journal as soon as possible." Later, the phase was also observed in American Laboratory. Professor Fidler, the famous scientist in microstructure and magnetic properties, indicated that in situ dynamic observation for diffusively continuous phase transition was the advanced work in the world.

While writing this book, the author recalled many scholars and specialists, who collaborated with the author in the studies of rare earth permanent-magnet alloys and high temperature phase transition during more than thirty years. Here the author expresses heartfelt thanks for their kind helps. They are Fengzuo Tian, Ansheng Liu, Guocheng Zhang, Jiguang Sun, Chengzhou Yu, Qiming Ying and Yujiu Liu in General Research Institute for Nonferrous Metal, Ruzhang Ma, Zuxiong Xu, Jueyun Ping and Zhengwen Li in Department of Materials Physics, Beijing University of Science and Technology, Yuefu Xiao, Shouzeng Zhou, Maocai Zhang, Zhengwen Li, Zhijun Zuo and Jianjun Tian in Department of Materials and Engineering, University of Science and Technology Beijing, and Baogen Shen, Guodong Li, Fuming Yang and Helie Luo in Institute of Physics Chinese Academy of Sciences, Yingchang Yang and Wending Zhong in Peking University, and Wei Li, Jinfang Liu and Youmei Li in General Research Institute of Iron and Steel, Zhenxi Wang, Boping Hu and Yang Luo in Sanhuan Company of Chinese Academy of Sciences, Hanming Jing in University of Jilin, Daku Sun and Guohua Chen in South-West Institute of Physics.

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tion while writing the book. Academician Guocheng Zhang, Professor Yang Luo and Shouzeng Zhou communicated with the author and proposed their viewpoints, and thus improving and richening the book. The editors of Metallurgical Industry Press, Xiaofeng Liu, Xiying Zhang and Yuan Zeng, do their conscientious work during publishing. General Research Institute for Nonferrous Metal and Metallurgical Industry Press and Springer Press offered their supports and encouragement during writing and publishing the book. The author must express deep gratitude to above all because their contributions are involved in the book.

March, 2012

Shuming Pan

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