Plasma Surface Metallurgy

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With Double Glow Discharge Technology —Xu-Tec Process

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I would like to dedicate this book to Dr. German Bernard Berghaurs, the inventor of plasma nitriding technology and a pioneer who had been first applying the glow discharge phenomenon to material surface alloying technology.
Innovative development of the plasma nitriding technology made it possible for me to invent the technology of Double Glow Discharge Plasma Surface Metallurgy.

David Zhong Xu
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Foreword

The modification of metal surfaces is used to increase surface hardness, improve interface interactions between separate surfaces (tribological interactions), and/or decrease surface chemical activity and degradation. Surface modifications can improve the performance and extend the life of basic materials, particularly those that have desirable bulk characteristics such as weight per volume, machinability, material cost, etc. The reference book, "Plasma Surface Metallurgy with Double Glow Discharge Technology", written by my good friend Prof. Zhong Xu and his colleagues, is to introduce this kind of surface metallurgical technology to our readers.

I met Prof. Xu in the United States in 1981. It was at this time that he began serious work on a "new" plasma technique based upon a double glow discharge process. The process has been shown experimentally and commercially to modify metal surfaces (and ceramic surfaces) to improve important parameters already noted. Additionally, the surface treatment alloy elements diffuse into the base metal to a sufficient depth and the modified surface layer attaches effectively to the base material such that the interface adhesion is extraordinary.

This book explains and describes the metallurgy, physics, and chemistry of this new technique and describes current and future application areas. Prof. Xu's technique was patented in many countries and is known as Xu-Tec. Numerous commercial products have been made and implemented using this process. The technique holds considerable potential for numerous applications, particularly for sheet steel and for many unique alloys such as titanium, molybdenum, tantalum, and super alloys, such as NiCrMoCu and NiCrMoNb, as well. Applications are reported for hardening stainless steel and for plasma surface metallurgy to produce antibacterial stainless steel surfaces.

The book is also a rather complete in-depth description of surface metallurgy in general. Chapters are included which describe and explain surface engineering and alloying technology including conventional techniques and plasma processing (including nitriding, carburizing, and sulphurizing). Additionally, ceramization on stainless sheet surfaces and treatment of ceramic surfaces are both described.

The book is particularly useful in that it describes industrial applications of Xu-Tec and performance which can be achieved in applications such as band saw blades and an industrial colloid mill. An application to produce corrosion resistant steel plate is also described. Double glow plasma surface metallurgy equipment and laboratory operation and commercial production are also described.

This book will be valuable to those in the general area of surface metallurgy. The substantial description of the Xu-Tec process is very important and should assist in expanding the use of this superior technique. The in-depth explanation of glow discharges and their use in general will also serve as a valuable reference in the field.

I congratulate Prof. Xu and his colleagues for their extraordinary technical and application contribution which will serve researchers and manufacturers for the future.

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of Mechanical and Aerospace Engineering
Fellow of the Institute of Electrical
and Electronic Engineers, University of Missouri
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Preface

The “Plasma Nitriding” process, invented by German Bernard Berghaus in 1930, was the first surface alloying technology where nitrogen gas glow discharge plasma was utilized. It is considered as one of the most important achievements in the surface metallurgical modification and “the foundation stone of modern plasma surface engineering”. Today, it has been widely used for surface nitriding treatment on metals and has generated huge economic profits and social benefits. However, in more than 50 years after its advent, plasma nitriding can only be applied to non-metallic elements, such as nitrogen, carbon, sulfur, etc.

Advanced on the plasma nitriding technology, a new surface alloying modification method, named the double glow discharge plasma surface metallurgy technology, has been invented by using the “Double Glow Discharge Plasma Process”.

In 1978, Prof. Zhong Xu discovered the “Double Glow Discharge Phenomenon” in his laboratory in Taiyuan University of Technology, China. Following this discovery, the “Double Glow Plasma Surface Metallurgy Technology” for the metal surface alloying modification was invented in 1980. Further development was advanced while Xu was visiting the USA and working in Prof. James Thompson’s Laboratory.

In the double glow discharge plasma surface alloying process, one set of Argon gas discharge plasma is employed for sputtering of a solid alloying target, while another set of glow discharge plasma is generated on the substrate surface for heating and alloying reaction. By this process, many chemical elements in the chemical element periodic table, including the solid metal elements and gaseous nonmetal elements, can be utilized for surface alloying on metals. The substrate surface heating and thermal drive interdiffusion of sputtering deposited alloying elements into the surface of substrate materials to form a surface alloy layer with enhanced interface adhesion.

Double glow plasma surface alloying technology was filed for an invention patent first in the United States of America in 1982 and granted in 1985. Afterwards, this technology, referred as the “Xu-Tec Process”, had attracted a great engineering interest in the materials industrial community upon its industrial application potentials. Several news and appraisal comments on this subject have

been reported. Later, the Xu-Tec has also patented world-widely in the United Kingdom, Canada, Australia, and Sweden et al.

In over almost 40 years after the invention, the experimental research results have demonstrated that the Xu-Tec process can be utilized with high feasibility for surface alloying modification of metals, to form many surface alloying layers with high hardness, wear resistance, resistance to corrosion on the surfaces of low-grade metal substrates. The substrate materials include titanium and titanium alloys, copper and copper alloys, intermetallic compounds, and other conductive materials. A gradient alloy ceramic layer (transferred from metal matrix to ceramic) can also be formed on the surface of metal material by this technology.

The Xu-Tec process has opened up a new material engineering field of "Plasma Surface Metallurgy". With this surface metallurgy process for material surface modification, it can transfer many low-grade and low-cost solid matrices of industrial engineering materials to be a "gold" material with a high value and high grade or special functions. This improved material would be widely used in industrial production to improve the surface performance and quality of mechanical parts and manufacturing products, and to conserve expensive alloying elements for the benefit of all mankind.

Taking many advantages of the Xu-Tec process, several industrial applications have developed. High-speed steel, stainless steel, nickel based alloys, and more complex composition alloys on the surfaces of steels have been produced. Surface alloying modification on cutting tools, chemical valves, colloid mills, large steel plates, and other industrial products was also demonstrated, with substantial improvement in their surface properties and quality of components for the mechanical manufacturing industry. The Xu-Tec process has been developed to be one of the most advanced, powerful, and practical surface alloying technologies in today's world. This technology has broad application prospects in machinery manufacturing, marine engineering, transportation, food processing equipment, household appliances, and the aerospace and defense industries.

The Xu-Tec process is a typical physical metallurgical technology, involving a series of advanced physical subprocesses such as vacuum and pressure control, double glow discharge and low-temperature plasma, material sputtering and physical vapor deposition, ion bombardment and plasma heating, thermal driven interdiffusion, and alloying formation. This technology has no chemical waste and no pollution (dust, liquid, gaseous). It is an environment-friendly and resource-saving surface alloying technology.

In addition to using the double glow discharge phenomenon for surface modification, a series of other new technologies for material treatments have been also developed, such as double glow plus arc discharge surface alloying, double glow brazing, double glow sintering, double glow nano-powder synthesizing, double glow diamond film growth, double glow surface cleaning, and more others.

The purpose of the book publication is to introduce the Xu-Tec technology to the world and promote further attention and interest for scientific research and engineering development, as well as industrial utilization and product commercialization. This book summarizes the technology development history, physical

mechanism, and research results of surface metallurgy with double glow plasma surface metallurgy. To this end, the book has also concentrated additional detailed understandings and experiences by numerous researchers and developers in this technology area.

There are numerous researchers and engineers, as well as Ph.D. students and professors who have given their substantial contributions to this technology development. We just could not list all their names here to show them our appreciations. However, we appreciate very much that this book has the following persons contributed in writing:

- Chapters 5 and 13—Pingze Zhang, Ph.D.
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- Chapter 9—Xiaoping Liu, Ph.D.
- Chapter 10—Wenping Liang, Ph.D.
- Chapter 11—Qiang Miao and Hongyan Wu, Ph.D.
- Chapter 12—Jun Huang, Ph.D.

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