



真空技术与表面工程

——第九届真空冶金与表面工程学术会议论文集

Vacuum Technology and Surface Engineering
Proceedings of the 9th Vacuum Metallurgy and Surface Engineering Conference

主 编：巴德纯

Editor in Chief: Ba Dechun

副主编：张世伟 刘 坤

Subeditor: Zhang Shiwei Liu Kun

中国·沈阳
Shenyang, China

真空技术与表面工程

——第九届真空冶金与表面工程学术会议论文集

Vacuum Technology and Surface Engineering
——Proceedings of the 9th Vacuum Metallurgy and Surface Engineering Conference

主 编：巴德纯
Editor in Chief: Ba Dechun

副主编：张世伟 刘 坤
Subeditor: Zhang Shiwei Liu Kun

电子工业出版社
Publishing House of Electronics Industry

北京·BEIJING

内 容 简 介

本书是 2009 年在中国沈阳举办的第 9 届真空冶金与表面工程学术会议的论文集, 收录了来自国内外的 102 篇投稿论文, 反映了近年来在真空冶金、表面工程和真空技术等领域的许多最新科研成果, 内容主要包括真空冶金、真空热处理、真空冶金涂层、表面改性技术、生物材料表面工程、纳米表面工程和纳米摩擦学、超薄薄膜与功能薄膜、气相沉积技术、摩擦学、腐蚀与防护、纳米新材料的真空制备技术、表面工程基本问题、真空技术及应用、真空设备故障诊断、大型真空冶金设备的自动化等, 可供从事真空工程、真空冶金、表面工程、真空应用等研究和应用领域的学者、技术人员和研究生参考。

This book gathers 102 pieces of papers from the 9th Vacuum Metallurgy and Surface Engineering Conference held in Shenyang China in 2009, which reflects many latest research achievements in such areas as vacuum metallurgy, surface engineering, vacuum science and technology in recent years. The papers mainly cover many subjects like refinement technique outside furnace, vapor deposition technology, vacuum melting technology, tribology, vacuum heat treatment, corrosion prevention, vacuum metallurgy coating, the vacuum fabrication technology of new nanometer material, surface modification technology, the basic problem of the surface engineering, the surface engineering of biological materials, vacuum science and technology, the nanometer surface engineering and nanometer tribology, fault diagnose to the vacuum equipments, superhard film and functional film, the automatization of large vacuum metallurgy equipments etc. As a good reference book, it is fir for scholars, technical personals and graduate students engaged in vacuum metallurgy, vacuum engineering, surface engineering, and vacuum applications.

未经许可, 不得以任何方式复制或抄袭本书之部分或全部内容。

版权所有, 侵权必究。

图书在版编目 (CIP) 数据

真空技术与表面工程: 第九届真空冶金与表面工程学术会议论文集: 英文/巴德纯主编. —北京: 电子工业出版社, 2009.8
(真空技术与表面科学)

ISBN 978-7-121-09341-8

I. 真… II. 巴… III. ①真空技术—学术会议—论文—英文②金属表面处理—学术会议—论文—英文③金属表面保护—学术会议—论文—英文 IV. TB7-53 TG17-53

中国版本图书馆 CIP 数据核字 (2009) 第 129831 号

责任编辑: 董亚峰

印 刷: 北京季蜂印刷有限公司

装 订: 北京季蜂印刷有限公司

出版发行: 电子工业出版社

北京市海淀区万寿路 173 信箱 邮编 100036

开 本: 880×1 230 1/16 印张: 35.5 字数: 1140 千字

印 次: 2009 年 8 月第 1 次印刷

定 价: 198.00 元

凡所购买电子工业出版社图书有缺损问题, 请向购买书店调换。若书店售缺, 请与本社发行部联系, 联系及邮购电话: (010) 88254888。

质量投诉请发邮件至 zltz@phei.com.cn, 盗版侵权举报请发邮件至 dbqq@phei.com.cn。

服务热线: (010) 88258888。

前 言

“真空冶金与表面工程学术会议”是由中国真空学会真空冶金专业委员会主办的学术年会，自 1978 年至今已举办了 8 届。2003 年起，改为每两年举办一次，该年会的目的是为真空冶金与表面工程领域的专家、学者、工程技术人员提供一个交流的平台，以推动我国该领域的科技发展和应用。

第 9 届中国真空冶金与表面工程学术会议于 2009 年 8 月 24~27 日，在辽宁沈阳东北大学举办。本次会议由东北大学真空与流体工程研究中心承办，邀请了国内外知名学者和专家将做十余场精彩的大会特邀报告。

截止到 2009 年 6 月 30 日，会务组共收到投稿论文 150 余篇。经大会学术委员会评审，论文集共收录 102 篇，论文作者包括来自中国、日本、韩国、澳大利亚等在内的多个国家和地区。

本次会议将开设真空冶金、表面工程和真空技术三个分会场的学术交流，还将组织参会代表赴相关进行企业考察，会议成为大学、研究部门和企业之间的桥梁。在举办过程中，会议得到了多家单位的支持和赞助，在此一并表示感谢。

感谢电子工业出版社的辛勤劳动和各位论文作者的出色工作，使得这本论文集得以付梓。论文集的出版与发行，将对我国真空冶金与表面工程领域的学术与技术交流的蓬勃发展起到重要的意义。

中国真空学会真空冶金专业委员会

2009 年 7 月 10 日

大会组织机构

学术委员会

戴永年	院 士	(昆明理工大学)
闻立时	院 士	(中科院金属研究所)
李正邦	院 士	(北京钢铁研究总院)
卡尔·劳	教 授	(美国莱斯大学)
杨乃恒	教 授	(东北大学)
姜燮昌	教 授	(中国真空学会)
薛增泉	教 授	(北京大学)
吴锦雷	教 授	(北京大学)
潘 峰	教 授	(清华大学)
巴德纯	教 授	(东北大学)
陈充林	教 授	(美国德州大学圣安东尼奥分校)
屠基元	教 授	(澳大利亚墨尔本皇家理工大学)
杨 斌	教 授	(昆明理工大学)
董 闯	教 授	(大连理工大学)
李争显	教 授	(西北有色金属研究院)
田修波	教 授	(哈尔滨工业大学)

组织委员会

主 任:	巴德纯	教 授	(东北大学)
副主任:	苏 原	教 授	(沈阳真空技术研究所)
	雷震霖	研究员	(国家真空仪器装置研制中心)
	杨 柯	研究员	(中科院金属研究所)
秘书长:	张世伟	副教授	(东北大学)
	刘 坤	博 士	(东北大学)

鸣 谢

爱发科中北真空（沈阳）有限公司

兰州真空设备有限责任公司

三特真空冶金技术工业（锦州）有限公司

中科院沈阳科学仪器研究中心有限公司

沈阳百乐真空技术有限公司

Appreciation and Thanks

ULVAC (Shenyang) Zhongbei Vacuum Tech. Co.,Ltd

LANZHOU Vacuum Equipments Co.,Ltd.

SANTE (Jinzhou)Vacuum Metallurgy Tech. Industry Co.,Ltd

SKY Technology Development of Chinese Academy of Sciences Co.,Ltd.

BELLA (Shenyang) Vacuum Tech. Co.,Ltd.

Preface

Vacuum Metallurgy and Surface Engineering Conferences are sponsored by the Vacuum Metallurgy Committee of Chinese Vacuum Society (CVS-VMC), which have been already held seven times since 1978. Moreover, the next conference was held every two years since 2003, which is to provide a chance for experts, scholars, technical engineers and etc. in these areas to communicate with each other, then as a result science and technology in these area can be rapidly developed .

The 9th Vacuum Metallurgy and Surface Engineering Conference will be held in June 16th to June 19th of 2009 in Shenyang, Liaoning Province of China. This conference is sponsored by Vacuum and Fluid Engineering Research Center of Northeastern University. About 10 well-known scholars or professors will give wonderful invited speeches at the conference.

Close till May 10, 2009, we totally received more than 150 articles and papers. This book gathered 102 pieces of papers selected by the Academia Committee. The Authors comes from several countries include China, Japan, Koran, Australia and etc.

There are three grouped conference include Vacuum Metallurgy, Surface Engineering, Vacuum Science and Technology. We also organized visits to some related factories. We hope that the meeting could become the bridge of universities, research departments, factories and enterprises. We should appreciate the support and sponsor of several enterprises.

Thanks for the hard work of Electronics Industrial Publication House and the outstanding work of each author, which make it become true that this book can be printed and issued. We also hope that our work will be meaningful for the academic and technical development of vacuum metallurgy and surface engineering.

CVS-VMC

July 10, 2009

Organizational Structure

Academic Committee

Prof. Dai Yongnian	(Kunming University of Science and Technology)
Prof. Wen Lishi	(Institute. of Metal Research Chinese Academic of Science)
Prof. Li Zhengbang	(Steel Research Institute of Beijing)
Prof. Carl Rau	(Rice University)
Prof. Yang Naiheng	(Northeastern University)
Prof. Jiang Xiechang	(Chinese Vacuum Society)
Prof. Xue Zengquan	(Beijing University)
Prof. Wu Jinlei	(Beijing University)
Prof. Pan Feng	(Tsinghua University)
Prof. Ba Dechun	(Northeastern University)
Prof. Chen Chonglin	(University of Texas at San Antonio)
Prof. Tu Jiyuan	(RMIT University)
Prof. Yang Bin	(Kunming University of Science and Technology)
Prof. Dong Chuang	(Dalian University Of Technology)
Prof. Li Zhengxian	(Northwest Institute for Non-ferrous Metal Research)
Prof. Tian Xiubo	(Harbin Institute of Technology)

Organizing Committee

Prof. Ba Dechun	(Northeastern University)
Prof. Su Yuan	(Institute. of Vacuum Research Chinese Academic of Science)
Prof. Lei Zhenlin	(National Research and Fabrication Center of Vacuum Equipments and Instruments of China)
Prof. Yang Ke	(Institute Of Metal Research Chinese Academy Of Sciences)
Dr. Zhang Shiwei	(Northeastern University)
Dr. Liu Kun	(Northeastern University)

目 录

第 1 部分 真空冶金

Part 1 Vacuum Metallurgy

Experimental Study on Extraction of Lithium by Vacuum Thermal Reduction with Ferro-silicon Alloy 硅铁真空热还原提取锂的实验研究	狄跃忠 董维维 武小雷 王紫千 冯乃祥 (3)
Calculation of the Crystal Location in Vacuum Thermal Process Producing Magnesium 热法炼镁过程中镁结晶位置的计算	武小雷 冯乃祥 张显鹏 程恩庆 施春辉 (8)
Study on TiC/Ni coating by Laser alloying In-situ Fabricated in the internal Surface of N80 Tubing N80 油管内壁激光原位合成 TiC/Ni 涂层研究	程义远 王 勇 韩 彬 李美艳 牛海洋 (12)
Effect of Ta interlayer on interdiffusion behavior of NiCrAlY coated γ -TiAl Ta 中间层对 γ -TiAl 和 NiCrAlY 涂层之间互扩散的影响	程玉贤 王 文 朱圣龙 王福会 (18)
Effect of Processing Parameters on Microstructure and Properties of Steel-based chromium plating 工艺参数对钢基镀硬铬层微结构与性能的影响	汤 卉 王 佳 赵 元 (22)
Theoretical Analysis and Experimental Study on Thermal Reduction of Calcined Dolomite with Al-Si-Fe Ternary Alloy Al-Si-Fe 三元合金热法炼镁的理论分析及试验研究	胡文鑫 刘 建 冯乃祥 彭建平 (27)
Microstructure and properties of high velocity arc-sprayed MMC coating 高速电弧喷涂 MMC 涂层的组织和性能研究	宋云京 邓化凌 石文华 (32)
Study on corrosion of superheater in the biomass-fired boilers 生物质燃烧锅炉过热器管腐蚀研究	宋云京 石文华 (35)
Reaction Mechanism of AlCl Generated by Carbothermic-chlorination to Produce Aluminum in Vacuum 真空碳热-氯化低价氯化铝歧解法炼铝的反应机理	袁海滨 杨 斌 郁青春 徐宝强 朱玉艳 冯月斌 戴永年 (39)
Properties of Ti-Al alloying layer on titanium alloy surface by double glow discharge plasma aluminizing 钛合金表面双层辉光渗铝形成钛铝合金层性能的研究	陈 飞 陈家庆 周 海 吕反修 (46)
Effects of slow shot speed of SSS die casting on microstructure and mechanical properties of aluminum alloys ADC12 超低速压铸慢压射速度下的 ADC12 铝合金组织和性能	纪莲清 吴 超 熊守美 村上正幸 松本悦豪 池田伸吾 (52)
Effect of alloy additives on the friction and wear properties of vacuum sintering FeAl matrix composite frictional materials 合金元素对真空烧结 FeAl 基摩擦材料摩擦学性能影响的研究	付传起 孙俊才 王 宙 (59)
Study of process and performance after combination surface treatment on 20 steel 20 钢复合表面处理技术的研究	杨英歌 周 海 陈 飞 万汉城 曾冬梅 冯文然 (64)

- Effect of high current pulsed electron beam treatment on microstructure and microhardness of hypereutectic Al-15Si alloy
强流脉冲电子束处理对过共晶铝硅合金 Al-15Si 微观组织及显微硬度影响研究
..... 高波 郝仪 涂贛峰 石为喜 李世伟 郝胜智 董闯 (68)
- Effect of Nd on Microstructure and Mechanical Properties Of Hypereutectic Al-17.5Si Alloy
稀土 Nd 对过共晶 Al-17.5Si 合金的微观结构和力学性能的影响
..... 高波 石为喜 涂贛峰 郝仪 吴官印 (75)
- Laser parameters on the surface of magnesium alloy AZ91D alloy modified layer of corrosion resistance
激光参数对 AZ91D 镁合金表面合金化改性层性能的影响 孙凯 杨森 刘凤霞 (80)
- Investigation of TiAlZrCr/(Ti, Al, Zr, Cr) N Gradient Films Deposited by Multi-arc Ion Plating
多弧离子镀 TiAlZrCr/(Ti, Al, Zr, Cr) N 梯度膜的研究 赵时璐 张钧 刘常升 (83)
- Diffuse Dynamics of Double Glow Plasma Hydrogen-Free Carburizing on Ti6Al4V
Ti6Al4V 双层辉光离子无氢渗碳扩散动力学 张高会 黄国青 于明洲 吴太全 张平则 (89)
- Study on Nonlinear Dynamics Characteristics of Vibration Pile Friction System with Slow-varying
振动沉桩摩擦系统慢变过程的非线性动力学特性研究 滕云楠 孙伟 任朝晖 闻邦椿 (94)
- Effect of carbon content on plasma nitrocarburising Characteristics of AISI304 austenitic stainless steel
碳含量对 AISI304 奥氏体不锈钢离子碳氮共渗性能的影响 张以忱 郭元元 马胜歌 耿漫 (98)
- The Interdiffusion Behavior Between Ti60 Titanium Alloy and Arc-ion Plating Ti-48Al-12Cr Coating
Ti60 钛合金与电弧离子镀 Ti-48Al-12Cr 涂层之间扩散行为 闫伟 王清江 孙凤久 刘建荣 (103)
- A Study of Aluminum Coating on Sintered NdFeB Magnet
烧结型 NdFeB 永磁体表面镀铝层的实验研究
..... 孙宝玉 巴德纯 徐孝荣 房也 段永利 岳向吉 连法曾 杨彬 (107)
- Research of Purification of Industrial Silicon by Molten Mg-Zn Alloy at Condition of Vacuum
真空下用镁-锌合金熔融提纯工业硅粉的研究 郭菁 邢鹏飞 韩志彪 涂贛峰 (112)
- Surface Modification of Al-17.5Si Alloy by High Current Pulsed Electron Beam
过共晶铝硅合金 Al-17.5Si 强流脉冲电子束表面改性研究
..... 高波 郝仪 田小梅 赵铁钧 涂贛峰 孙树臣 邢鹏飞 (117)
- The Properties of Superhard Aluminium Alloy Implanted with Nitrogen by High Frequency and Low Voltage Plasma
Immersion Ion Implantation
高频低压氮等离子体浸没离子注入超硬铝合金表面改性研究
..... 邹晔 苏永要 冷永祥 孙鸿 黄楠 李树勇 谭云 (123)
- The Behavior of Silicon Dioxide in The Process of Aluminum Metallurgy in Low Valence Method
二氧化硅在低价氟化法炼铝过程中的行为 李秋霞 杨斌 戴永年 (129)
- Experimental Research on Preparation of Red Phosphorus with Phosphorus Ores in Vacuum
真空法由磷矿石一步制备红磷 李秋霞 夏利梅 李琮 荆碧 王宇飞 (135)
- Numerical Simulation of RH-refining Processes with Different Parameters of Snorkels
RH 真空精炼环流管参数对循环流动影响的数值模拟 王晓冬 张宇 (138)
- Operation Skills of making Ultra-low Carbon Steel in RH vessel
真空炉生产超低碳钢的实践操作 吴全明 (143)
- TEM analysis of the micro-arc oxidation coatings on magnesium alloys in a aluminate alkaline electrolytic solution
铝酸盐电解液中镁合金微弧氧化 TEM 分析 陈显明 罗承萍 刘江文 (147)
- Research of Producing Titanium Powder by Calciothermic-reduction Process from Titanium Dioxide
金属钙热还原二氧化钛制取金属钛粉的实验研究 宋建勋 徐宝强 杨斌 林大志 郁青春 (152)

The Influence of Nitrogen Plasma Ion Immersion Implantation and Artificial Aging on The Mechanical Properties of LC4 Aluminum Alloy

氮等离子体浸没离子注入及人工时效对 LC4 铝合金机械性能的影响
..... 苏永要 邹 颀 包娟娟 冷永祥 孙 鸿 黄 楠 李树勇 谭 云 (159)

Physical Simulation for Mixing and Mass Transfer Characteristics during RH Vacuum Refining Process
RH 真空精炼过程混合及传质特性的物理模拟 耿佃桥 雷 洪 刘爱华 赫冀成 俞 洋 于 雷 (164)

Laser in-situ reaction cladding of titanium boride/titanium composite on titanium substrate
钛基体上激光原位反应熔覆硼钛化物/钛复合涂层 丁龙先 NAKASAKI KATO M (169)

Corrosion Research of Aeroconcrete Steam Autoclave
加气混凝土蒸压反应釜的腐蚀治理与研究 张志军 曹露春 (175)

Numerical Simulation and Experimental Study of Flow and Temperature Fields during Vacuum High-Pressure Gas Quenching
真空高压气淬过程流场温度场数值模拟和实验研究 王志坚 王贺权 徐成海 (181)

Numerical Simulation of Different Wind Tunnel Flow Types in Vacuum High-pressure Gas Quenching Furnace
真空高压气淬设备不同风道流动型式的数值模拟 王志坚 王贺权 徐成海 (187)

第 2 部分 表面工程

Part 2 Surface Engineering

Study Of Stress in TiO₂ films grown by electron-beam evaporation
电子束蒸发制备二氧化钛薄膜的应力研究 陈 焘 罗崇泰 王多书 熊玉卿 (195)

Nanocrystalline TiN coating prepared by reactive plasma spraying
反应等离子喷涂制备纳米晶 TiN 涂层 冯文然 周 海 杨英歌 曾冬梅 卢一民 万汉城 (201)

Adhesion characteristics of an epoxy coating on different substrates
一种环氧有机涂层在不同基材表面附着性能的研究 付东兴 徐滨士 张晓因 杨中元 (206)

Preparation and Properties of Electrochromic Thermal Control Thin Film
电致变色热控薄膜的制备与性能 何延春 邱家稳 许 旻 王洁冰 吴春华 赵印中 (211)

Effect of sintering parameters on friction wear behavior of graphite/copper composites
烧结工艺参数对石墨/铜基复合材料摩擦磨损行为的影响 金永平 项 春 崔梁萍 郭 斌 (215)

Blue Photoluminescence from Cerium Ions Doped Aluminum Oxide Films by Medium Frequency Reactive Magnetron Sputtering
中频反应磁控溅射制备 Al₂O₃:Ce³⁺ 薄膜的蓝色发光特性 廖国进 骆 红 闫绍峰 陈 明 戴晓春 (221)

Research on Cryogenic Mechanical Properties of Nanomaterial Modified Epoxy Resin
纳米材料改性环氧树脂低温力学性能研究 刘建秀 宁向可 刘永军 (227)

Synthesis of high texture orientated Ni-Co-Fe₂O₃ composite coatings by electrodeposition
复合电沉积制备高织构 Ni-Co-Fe₂O₃ 复合涂层 马 莉 周科朝 李志友 (231)

Effect of PbTe Quantum Dots on Electrical Performances of Bi₂Te₃ Thermoelectric Films
PbTe 量子点对 Bi₂Te₃ 热电薄膜电学性能的影响研究 穆武第 程海峰 唐耿平 (237)

Numerical study on the mixing effects of double-layer target irradiated by high-intensity pulsed ion beam
强流脉冲离子束辐照混合双层靶的数值研究 吴 迪 张建红 王 静 雷明凯 官 野 (243)

Study on electrical property of alumina gel-TiB₂ cathode material
氧化铝凝胶-硼化钛阴极材料的电性能研究 俞小花 谢 刚 吕 霖 王达健 李荣兴 李永刚 (248)

Cd_{1-x}Zn_xTe alloy films grown by r.f.sputtering射频磁控溅射法制备 Cd_{1-x}Zn_xTe 薄膜 曾冬梅 周海 孙金池 杨英歌 冯文然 万汉城 卢一民 (253)

Research on Film Thickness Uniformity of Sputtering Deposition on Planar Substrate

平板基片溅射镀膜的膜厚均匀性研究 张以忱 宋青竹 (259)

Synthesis and tribological properties of diamond-like carbon films prepared on stainless steel by RFPECVD process

采用射频等离子体增强化学气相沉积方法在不锈钢上制备类金刚石碳(DLC)膜的工艺及性能
..... 蔺增 王芳 岳向吉 张以忱 巴德纯 In-Seop Lee (270)

Microstructure and Magnetostriction of Sm-Fe GMFs

Sm-Fe GMFs 的组织结构与静态磁致伸缩性能 周白杨 骆汉彬 (277)

Design of sputtering vacuum machine based on the Atemga128

基于 Atemga128 的磁控溅射镀膜机 刘艳涛 马剑平 (282)

Preparation of quartz resonators with Pulse Magnetron Sputtering Technology

脉冲溅射技术制备石英谐振器的工艺研究 刘艳涛 马剑平 (287)

Residual Stress reduction of c-BN Films with one BN_x Interlayer Deposited by RF Magnetron SputteringBN_x 过渡缓冲层对磁控溅射 c-BN 薄膜残余应力的影响研究 蔡志海 张平 赵军军 杜军 (292)

Use a theoretical model to investigate reactive sputtering of AlN thin films

应用模型研究反应溅射制备 AlN 薄膜过程 佟洪波 柳青 (297)

The role of parameters in arc deposition of ZrN films

电弧沉积 ZrN 涂层影响因素分析 杜军 张平 蔡志海 赵军军 田飞 (301)

Photoluminescence Properties of LaPO₄:Eu³⁺ Nanoparticles Synthesized by Oxalate Coprecipitation MethodLaPO₄:Eu³⁺ 纳米晶的草酸盐沉淀法合成及其发光性质 代雪晶 汤澄清 (306)

Vacuum Metal Deposition for Development of fingerprints: Influence of Quantities of Gold on Size and

Density of Clusters

真空金属镀膜显现指印: 镀金量对镀层尺寸和密度的影响 汤澄清 代雪晶 (312)

Study on multi-element penetrating property of low temperature gas on the surface of 27SiMn steel

27SiMn 钢表面低温气体多元共渗性能的研究 周海 陈飞 万汉城 戴志旺 (317)

Optical properties of aluminium oxide thin films prepared at room temperature by the medium frequency reactive magnetron sputtering system

溅射制备的 Al₂O₃ 薄膜的光学性质 廖国进 骆红 闫绍峰 陈明 戴晓春 (322)

Analysis on the morphology and progress of ZrN coating in salt water

Zr 基氮化物涂层的耐盐水腐蚀性能 杜军 张平 赵军军 蔡志海 田飞 (329)

Study on Double Layers Anti-Reflection Coating of SiO₂/TiO₂ by Magnetron Sputtering磁控溅射制备 SiO₂/TiO₂ 双层减反射薄膜的研究 王贺权 王志坚 巴德纯 沈辉 闻立时 李运强 (334)

Study of uranium thin film prepared by high vacuum magnetron-sputtering method

高真空磁控溅射法沉积铀薄膜 陈秋云 赖新春 黄火根 罗丽珠 蒋春丽 谭世勇 (340)

Optical Properties of a-Al₂O₃ Films Deposited by MF Magnetron Sputtering溅射制备 Al₂O₃ 薄膜的光学性能研究 闫绍峰 骆红 (344)Study on Double Layer Anti-Reflection Coating of TiO₂/TiO₂单质 TiO₂ 双层减反射薄膜的实验研究 王贺权 王志坚 巴德纯 沈辉 闻立时 李运强 (352)

Discharge Characteristics Induced By Self-Excited by Radio Frequency During Plasma Ion Implantation of
Cylindrical Bore
等离子体离子注入管筒内壁自激射频放电等离子体特性…………… 巩春志 田修波 朱宗涛 杨士勤 (358)

Investigation of structural, mechanical, and tribological properties of CrTiAlN composite coatings deposited on
piston rings
活塞环表面 CrTiAlN 复合膜的结构、力学性能与摩擦学性能研究…………… 蔡志海 张平 杜军 赵军军 (362)

The Barrier Mechanism Research of The Ceramic Thin Film by Plasma Auxiliary Magnetron Sputtering
等离子辅助磁控溅射陶瓷薄膜阻隔机理的研究…………… 刘壮 林晶 孙智慧 (367)

Study by Means of IR and XPS of Al_xO_y Barrier Films On PET Substrate Prepared by PVD
PVD 法制备 SiO_x/PET 阻隔膜的 IR 及 XPS 研究…………… 林晶 孙智慧 刘壮 (372)

第 3 部分 真空技术

Part 3 Vacuum Technology

Numerical Study on Performances of Steam-jet Pump at Different Operating Conditions
水蒸气喷射泵操作参数对泵特性影响的数值模拟…………… 王晓冬 骆美玲 Sherman C.P. Cheung J.Y. Tu (379)

Preparation of high- purity indium by vacuum instillation
真空蒸馏法制备高纯铟…………… 邓勇 杨斌 刘大春 徐宝强 冯同春 (384)

Fire Resistance Performance Study of Titanium Alloy Surface
钛合金表面阻燃性能研究…………… 黄国青 张高会 张平则 徐鹏 于明州 吴太权 陈苗根 (390)

A new method of calculating the coiling diameter in the coiler system
卷取机卷径计算新方法…………… 安连祥 刘新艳 金斌 蔡召君 (395)

Analysis of failure modes for scroll wrap in scroll vacuum pump
涡旋真空泵涡旋齿失效形式分析…………… 强建国 (401)

Virtual Manufacturing of TMP Rotor Based on UG CAM
基于 UG CAM 的涡轮转子虚拟加工…………… 王晓冬 齐鹏 (407)

Manufacture of Double Draught Canister Composite Molecule Pump
双筒牵引复合型分子泵的研制…………… 常学森 靳毅 罗宁 (413)

Simulation for Single Crystal Aluminum Nanoindentation and its Experiment Research
单晶铝纳米压痕仿真及其实验研究…………… 朱瑛 刘倩倩 (417)

Design of optical filters by the concept of photonic crystal
一种双通道窄带滤光片的设计与制备…………… 王济洲 熊玉卿 刘宏开 陈焘 (422)

Study on the thermodynamic and experimental carbothermic reduction magnesia
真空对氧化镁碳热还原影响分析…………… 郁青春 杨斌 刘大春 徐宝强 李志华 戴永年 (428)

An Optimization Method to Overcome the Thickness Effect to Dual-Energy Transmission Imaging
克服厚度对双能量透射图像影响的最优化方法…………… 孙丽娜 (434)

The Excavating Robot's Adaptive Fuzzy Sliding Mode Control
挖掘机器人的自适应模糊滑模控制…………… 刘阔 刘坤 郭大猛 何欣欣 (442)

The application and development of the hull anticorrosion technology
船体防腐蚀技术应用及发展趋势…………… 许友林 姚智刚 张汝政 (448)

- Improved Method of Image Procession to Recognition The End of Stick-Material
棒线材端头识别图像处理改进方法 孙丽娜 (453)
- Non-separated Oil-consuming Analysis Instrument by virtual Instrument and ultrasonic measuring
基于超声波及虚拟仪器的汽车不解体油耗检测系统 孙丽娜 原培新 (460)
- Representation of Object Classification Curve by Dual-Energy X-ray Transmission Technology
双能量 X 射线透射条件下物质分类识别曲线的建立 孙丽娜 (467)
- Experimental study on vacuum freeze-drying of *Spirulina platensis*
螺旋藻真空冷冻干燥实验研究 彭润玲 徐成海 张世伟 李成华 李全顺 (472)
- Numerical Simulation of Thermobaric Explosive Overpressure field
温压药剂静爆超压场的数值模拟 赵新颖 李秀丽 吴春梅 (477)
- Research and Development of Hot-dip Zinc-coated Steel
钢材热浸镀技术的研究和进展 邢鹏飞 涂贇峰 (481)
- A rise in temperature induced by ion implantation of high beam current density
强束流离子注入引起的温升研究 李 颂 于义超 杨建华 罗达峰 (485)
- Study on Cleanliness of gas cylinder steel during Vacuum Degassing
真空脱气过程中气瓶钢洁净度研究 杨树峰 李京社 林晓川 姜桂连 (490)
- Study on Design and Deposition of Minus Filters for Laser Protection Application
激光防护用负滤光片设计与镀制 张佰森 马勉军 熊玉卿 陈 焘 叶自煜 (494)
- Study on Carbothermic Reduction of Titanium Dioxide in Vacuum
二氧化钛真空碳热还原实验研究 徐宝强 杨 斌 何剑萍 森 维 戴永年 刘大春 (499)
- Investigation of the Radial Clearance Leakage in Rolling Piston Compressors Based on CFD
基于计算流体力学的滚动活塞压缩机径向间隙泄漏研究 岳向吉 巴德纯 王 斐 张 宇 苏征宇 (506)
- State-of-art of Slip Flow in Nanochannel
纳米通道滑移流动的研究进展 张晓玲 刘 坤 李 涛 肖 玉 巴德纯 吴春梅 (512)
- Research of Ion Transport in Nanofluidic Channels far from Equilibrium
非平衡态下纳流控通道中离子输运的研究 刘 坤 李 涛 肖 玉 巴德纯 吴春梅 (517)
- Construction and Design of Split Flow Molecular Vacuum Pump Fit to Pumping in Differential Inlet Pressure
适合于差动抽气的分流分子泵的结构与设计
..... 刘 坤 吴春梅 赵隆超 陈 瑶 李培印 顾晓光 巴德纯 杨乃恒 (525)
- Simulation of temperature field in the rapid solidification process of Nd-Fe-B based on ANSYS
钕铁硼快速凝固过程温度场 ANSYS 模拟 房 也 巴德纯 张以忱 杜文强 孙宝玉 (529)
- The Influence of Vacuum Freeze-drying Technological Parameters on the Activity of Nattokinase
真空冷冻干燥工艺参数对纳豆激酶活性的影响 彭润玲 徐成海 张世伟 李成华 寇 巍 (533)
- Application and Current Situation of Steam Ejector Pump
水蒸汽喷射泵的应用与研究现状 林丽生 廖国进 (539)
- Research on Vibrating Spin-drier of Two-way and Half-spiral
双向半螺旋振动脱水机的研究 江 晶 谢元华 韩 进 王 磊 (545)
- The development of Numerical Simulation System of Carbon Concentration Distribution in Carburized Layer of the Usual Carburized Materials
常用合金渗碳材料碳分布数值模拟系统开发 虞莉娟 熊惠民 程晓敏 (549)

第 1 部分 真空冶金

Part 1 Vacuum Metallurgy



Experimental Study on Extraction of Lithium by Vacuum Thermal Reduction with Ferro-silicon Alloy

DI Yue-zhong DONG Wei-wei WU Xiao-lei WANG Zi-qian FENG Nai-xiang

(School of Materials and Metallurgy, Northeastern University, Shenyang 110004, China)

Abstract: Extraction of lithium by vacuum thermal reduction may be used extensively in future. Influences of various technological parameters such as reaction temperature and time on thermal decomposition of lithium carbonate and Lithia reduction were investigated in the of extraction of lithium by vacuum thermal reduction with Ferro-silicon alloy. On the best condition obtained by $L_9(4^3)$ orthogonal test, the decomposition efficiency of lithium carbonate could be above 99%. With increasing reduction temperature, the reduction rate could be reach up to 95.85% at 1293K. The reduction rate increased gently when the reaction time excess 120min.

Keywords: vacuum; lithium; decomposition; reduction

硅铁真空热还原提取锂的实验研究

狄跃忠 董维维 武小雷 王紫千 冯乃祥

(东北大学材料与冶金学院, 辽宁 沈阳 110004)

摘要: 真空热还原是目前较有前景的生产金属锂的方法。研究了以硅铁合金为还原剂制取金属锂的过程中, 反应温度和时间对碳酸锂分解和氧化锂还原率的影响。通过 $L_9(4^3)$ 正交实验获得碳酸锂分解的最佳条件, 分解率可达 99%以上。在研究范围内, 随着温度升高金属锂还原率显著提高, 1293K 时可达 95.85%; 反应时间超过 120min, 还原率增加趋于平缓。

关键词: 真空; 锂; 分解; 还原

1 Introduction

The lightest of all metals, lithium is used in a variety of applications, including petrochemical industry, lubricating material, synthetic rubber, glass ceramic. Nowadays it is called energetic metal of 21 century used extensively in the areas of aviation, nuclear-generated power and electric battery industry [1].

Nowadays, molten salt electrolysis and vacuum thermal reduction are main method of producing lithium. Over 90% of the world's primary lithium is produced by electrolyze LiCl-KCl molten salt system^[2-3]. The technology of electrolysis is very sophisticated, but its development will be effected by some factors: high-purity LiCl as raw material is very expensive; chlorine from anode pollutes environment; natrium content of lithium produced by electrolysis is too high. Vacuum thermal reduction may be used extensively in future because of low-energy consumption, high-purity and short-cycle. In this experiment, metal lithium was extracted by vacuum thermal reduction with Ferro-silicon alloy^[3-4].