Lecture Notes in Mechanical Engineering

Numan M. Durakbasa
M. Güneş Gençyılmaz *Editors*

Digital Conversion on the Way to Industry 4.0

Selected Papers from ISPR2020, September 24–26, 2020 Turkey

Springer

Lecture Notes in Mechanical Engineering

Lecture Notes in Mechanical Engineering (LNME) publishes the latest developments in Mechanical Engineering—quickly, informally and with high quality. Original research reported in proceedings and post-proceedings represents the core of LNME. Volumes published in LNME embrace all aspects, subfields and new challenges of mechanical engineering. Topics in the series include:

- Engineering Design
- Machinery and Machine Elements
- Mechanical Structures and Stress Analysis
- Automotive Engineering
- Engine Technology
- Aerospace Technology and Astronautics
- Nanotechnology and Microengineering
- Control, Robotics, Mechatronics
- MEMS
- Theoretical and Applied Mechanics
- Dynamical Systems, Control
- Fluid Mechanics
- Engineering Thermodynamics, Heat and Mass Transfer
- Manufacturing
- Precision Engineering, Instrumentation, Measurement
- Materials Engineering
- Tribology and Surface Technology

To submit a proposal or request further information, please contact the Springer Editor of your location:

China: Dr. Mengchu Huang at mengchu.huang@springer.com
India: Priya Vyas at priya.vyas@springer.com
Rest of Asia, Australia, New Zealand: Swati Meherishi at swati.meherishi@springer.com
All other countries: Dr. Leontina Di Cecco at Leontina.dicecco@springer.com

To submit a proposal for a monograph, please check our Springer Tracts in Mechanical Engineering at http://www.springer.com/series/11693 or contact Leontina.dicecco@springer.com

Indexed by SCOPUS. The books of the series are submitted for indexing to Web of Science.

More information about this series at http://www.springer.com/series/11236

Numan M. Durakbasa · M. Güneş Gençyılmaz
Editors

Digital Conversion on the Way to Industry 4.0

Selected Papers from ISPR2020, September 24–26, 2020 Online - Turkey

Springer

Editors
Numan M. Durakbasa
Research Group for Production Metrology and Adaptronic Systems
TU Wien (Vienna University of Technology)
Vienna, Wien, Austria

M. Güneş Gençyılmaz
Faculty of Engineering, Industrial Engineering Department
İstanbul Aydın University
İstanbul, Turkey

ISSN 2195-4356 ISSN 2195-4364 (electronic)
Lecture Notes in Mechanical Engineering
ISBN 978-3-030-62783-6 ISBN 978-3-030-62784-3 (eBook)
https://doi.org/10.1007/978-3-030-62784-3

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

Dear Colleagues and Friends,

It is a great pleasure to welcome you to the "**International Symposium for Production Research - ISPR 2020**", Antalya/Turkey, from 24–26 September 2020, with the overall theme of "Digital Conversion on the way to Industry 4.0". As in all previous years we are particularly pleased with our continued successful collaboration with Society for Production Research, İstanbul, Turkey, in the organization of this event.

The purpose of the symposium is to bring together researchers, scientists and leading world experts at universities, companies, institutions, communities, associations and societies in the domain of interest from around the world to share ideas, experiences, research results and vision on production and operations management and technology. This organization shall also provide a forum for experts and professionals to discuss the challenges, opportunities and advance innovation of the theme of this year's symposium.

We hope that this "on-line" gathering will provide the participants an opportunity for scholarly exchange of ideas and questions despite the absence of physical presence and face-to-face discussions. We wish you all a productive symposium and we sincerely hope that this pandemic will be behind us soon and that we can all go back to our regular format of conferences and symposia in the near future.

September 2020

Kurt Matyas
Ayhan Toraman

Preface

This book consists of the selected papers presented at the **20th International Symposium for Production Research (ISPR2020)** that would have been held from September 24–26, 2020, at a beautiful resort in Antalya, Turkey. Unfortunately, this event, like many others in all corners of the world, had to be converted to a virtual symposium due to the COVID-19 pandemic. Thanks to the magnificent improvements in Internet technologies we could easily switch our face-to-face meetings to virtual events with the aid of a user-friendly software program. This technical support was provided generously by the Vice-Rectorate for Digitalization and Infrastructure of TU Wien and our heartfelt thanks and gratitude go to Univ. Prof. Dipl. -Ing. Dr.techn. Dr.h.c.mult. Josef Eberhardsteiner, Vice-Rector.

This symposium was organized by Society for Production Research İstanbul, Turkey, and TU Wien, Austria, for the fourth year in a row.

The generic theme of "**Industry 4.0**" was first adopted in the symposium held in 2016 and maintained in the following four symposiums in 2017, 2018, 2019, and 2020 but each time with an updated emphasis on the relevant developments and progress on the various aspects of this "Fourth Industrial Revolution." In other words, the symposiums maintained the same main theme from 2016 but studied a different aspect of production systems and production management, in the subsequent years with the purpose of drawing the attention of the researchers to the cases of Industry 4.0 applications of this new industrial era.

The world of science and technology is under increasing influence of the requirements of Industry 4.0. Transition to a new era seems inevitable for every sector of industry. Given the importance of this theme, ISPR2020 hosted numerous distinguished speakers from both the academia and the industry to hear their views on the applications of the Industry 4.0 on the various components of production systems.

A total of over 350 participants attended this year's symposium—academics, practitioners, and scientists from 17 countries, 10 invited speakers made invaluable contributions to the symposium. The symposium programme included keynote addresses (opening/closing session), breakout sessions and workshop discussions, a welcome concert, and a closing session on the final day.

This book contains 83 refereed selected papers in 22 categories shown in the contents of the book.

We would like to express our gratitude to Vice-Rector Prof. Kurt Matyas, also the Honorary Chairman of the Scientific Committee of this symposium for his leadership and generous support. We also thank to Prof. Dr. Ayhan Toraman, Past President of Society of Production Research and Honorary Chairman of the Scientific Committee; Prof. Christian Bauer, Dean of the Faculty of Mechanical and Industrial Engineering; Prof. Detlef Gerhard, former Dean of the Faculty of Mechanical and Industrial Engineering; and Prof. Friedrich Bleicher, Head of the Institute for Production Engineering and Photonic Technologies for their interest and support for this symposium.

We would like to thank all the keynote and invited speakers whose contributions enhanced the success of the symposium.

In organizing this event, our colleagues in Vienna and İstanbul contributed endless hours of hard work, energy and wisdom to make this event the success it was. On the Vienna side, our sincere thanks go to the staff of the Research Group Production Metrology and Adaptronic Systems of the Institute for Production Engineering and Photonic Technologies, in particular, to Dipl.-Ing. Erol Güçlü.

On the İstanbul side, we are very grateful to Assis. Prof. Dr. Nükhet Tunçbilek who were involved in every aspect of the organization from the very beginning. Our special thanks go to Ms. Tuğçe Beldek and Mr. Aziz Kemal Konyalıoğlu, our young colleagues, research assistants, and Ph.D. candidates at İstanbul Technical University and Galatasaray University and Comp. Eng. Tufan Tunçbilek who prepared and managed virtuall event together with Dipl. Ing. Erol Güçlü perfectly and, also research assistants at TU Wien, for their hard and dedicated work. We would like to thank to Prof. Dr. Hatice Camgöz Akdağ and Assist. Prof. Dr. Zeynep Girgin who moderated the symposium successfully.

We would like to express our gratitude to the board members of the Society for Production Research in İstanbul for their strong support and dedication to make the symposium a success.

Our very special thanks go to our colleagues, the participants of this symposium. Undoubtedly, they were the core component of this organization.

We would like to recognize and thank our dear colleagues who graciously accepted to join the honorary and scientific committees or who served as peers in this event.

Finally, no such event is possible without the generous support of patrons and sponsors. In this regard, we would like to thank Dr. Michael Ludwig, the Mayor of Vienna, for his continued generous support of this symposium series and to all the corporations and individuals who provided invaluable financial and intellectual contributions.

And last but not least, we are grateful to Ms. Petra Jantzen Editor from Springer Nature, for her competent guidance, professionalism, and patience.

M. Güneş Gençyılmaz
Numan M. Durakbasa

Key Technology Roadmap In Production of Future – Industry 4.0

Today, Industry 4.0 is spreading more and more worldwide to industrial companies and especially to SMEs. With a strong infrastructure and a rapid connection between the components of the entire factory, Industry 4.0 will introduce innovation and more robust, reliable, and sustainable production. Smart economic growth, which is based on high-quality training and on the promotion of research and innovation as well as the building of digital factories, is most crucial and central to the future developments. This will ensure a sustainable development which respects the ecology by using green technologies and which will improve the working environment thus creating new and better jobs for a wider population.

Comprehensive knowledge in the areas of market requirements, product and process development and design, intelligent metrology, and end-of-life management are important conditions to achieve rapid, agile, waste-free, and cost-effective production of innovative, customized complex products using next-generation materials. This will also protect the environment by making zero emissions and improve environmental sustainability and reduce the use of energy within the factory of futures.

Cyber-physical systems (CPS) improve resource productivity and efficiency and enable more flexible models of work organization. Companies that use CPS will have a clear advantage when it comes to recruiting the best employees since they can offer a better work–life balance. Augmented reality (AR) and multimodal interaction will be used to train the factory workers so that they will be able to deal with the complexity of cyber-physical production and enable new forms of collaboration by digital systems. The smart factory concept which includes the need for closer interaction with tele-operation and tele-presence as part of the process in networked production centers will spread to industrial companies worldwide.

The application of artificial intelligence (AI) in the production field has also imposed new technological demands. To meet the market demands in present and future global industrial world manufacturing enterprises of any kind and any size must be flexible and agile enough to respond quickly to product demand changes. With support of artificial intelligence and modern information technology, it is possible to realize modern, cost-effective, customer-driven production considering the importance and basic role of integrated systems and advanced technology.

This new concept, according to Industry 4.0, can be developed on the basis of advanced production systems and multi-functional integrated factory model as well as extensive use of the IT, AI, CPS, simulation, virtual reality (VR), intelligent quality systems, automation, robotics, sophisticated metrology, and advanced engineering data exchange techniques.

September 2020

Numan M. Durakbasa
M. Günes Gencyilmaz

Organization

ISPR2020 was organized by TU Wien, Austria, and the Society for Production Research, Turkey. The symposium took place in Turkey.

Editors

Numan M. Durakbasa
M. Güneş Gençyılmaz

Co-editors

Peter Kopacek
Ayhan Toraman
Selim Zaim
Jorge Martin Bauer
Serpil Erol
Semra Birgün
Kemal Güven Gülen
Jan Torgersen
Alptekin Erkollar
Mahmut Tekin

Honorary Chairs

Kurt Matyas	TU Wien, Austria
Ayhan Toraman	Society for Production Research, Turkey

Symposium Chairs

Numan M. Durakbasa	TU Wien, Austria
M. Güneş Gençyılmaz	İstanbul Aydın University, Turkey

International Honorary Committee

Albert Weckenmann	Friedrich Alexander Universität Erlangen, Germany
Alice E. Smith	Auburn University, USA
Andrew Kusiak	The University of Iowa, USA
Christian Bauer	TU Wien, Austria
Daniela Popescu	Technical University of Cluj Napoca, Romania
Detlef Gerhard	Ruhr-University Bochum, Germany
Duc Truong Pham	The University of Birmingham, UK
Friedrich Bleicher	TU Wien, Austria
Lubomir Šooš	Slovak University of Technology Slovakia
Sorin Popescu	Technical University of Cluj-Napoca, Romania
Stanislaw Adamczak	Kielce University of Technology, Poland
Vidosav Majstorovic	University of Belgrade, Serbia

Organizing Committee

Selim Zaim, Turkey
Güneş Gençyılmaz, Turkey
Erol Güçlü, Austria
Semra Birgün, Turkey
Serpil Erol, Turkey
Berna Dengiz, Turkey
Kemal Güven Gülen, Turkey
Alptekin Erkollar, Turkey
Mahmut Tekin, Turkey
Eva Maria Walcher, Austria
Ferhan Çebi, Turkey
Dursun Delen, USA
Günther Poszvek, Austria
Şakir Esnaf, Turkey
Alp Baray, Turkey
Lukas Kräuter, Austria
Nükhet Tunçbilek, Turkey
David Riepl, Austria
Alp Baray, Turkey
Hatice Camgöz Akdağ, Turkey
Haluk Soyuer, Turkey
Hür Bersam Bolat, Turkey
Ece Soyuer, Austria
Jorge Bauer, Austria
Tuğçe Beldek, Turkey
Aziz Kemal Konyalıoğlu, Turkey
Liane Höller, Austria
Gökçen Baş, Austria
Gamze Uğur Tuncer, Austria

This book is prepared for publishing by

Tuğçe Beldek, Turkey
Aziz Kemal Konyalıoğlu, Turkey

Scientific Committee

S. Adamczak	Kielce University of Technology, Poland
H. Camgöz Akdağ	Technical University, Turkey
A. Akdoğan	Yıldız Technical University, Turkey
K. Altinel	Bosphorus University, Turkey
İ. Ar	Yıldırım Beyazıt University, Turkey
B. Baki	Karadeniz Technical University, Turkey

Ş. Baray	İstanbul University, Turkey
G. Baş	TU Wien, Austria
N. Başoğlu	İzmir Institute of Technology, Turkey
J. Bauer	National Technological University Buenos Aires, Argentina
A. Baykasoğlu	Dokuz Eylül University, Turkey
E. Bayraktar	The American University of the Middle East, Kuwait
F. Berto	Norwegian University of Science and Technology, Norway
S. Birgün	İstanbul Gedik University, Turkey
P. Blecha	Brno University of Technology, Czechia
F. Bleicher	TU Wien, Austria
H. B. Bolat	İstanbul Technical University, Turkey
F. Bozbura	Bahçeşehir University, Turkey
İ. Böğrekci	Adnan Menderes University, Turkey
I. Budak	Faculty of Technical Sciences in Novi Sad, Serbia
A. Bulgak	Concordia University, Canada
İ. Çavuşoğlu	Marmara University, Turkey
L. A. Crisan	Technical University of Cluj Napoca, Romania
F. Cus	University of Maribor, Slovenia
F. Çebi	İstanbul Technical University, Turkey
D. Delen	Oklahoma State University, USA
M. Demirbağ	University of Essex, UK
P. Demircioğlu	Adnan Menderes University, Turkey
B. Dengiz	Başkent University, Turkey
T. Dereli	İskenderun University, Turkey
M. Dinçmen	İstanbul Technical University, Turkey
M. Dragomir	Technical University of Cluj Napoca, Romania
Á. Drégelyi Kiss	Óbuda University, Hungary
N. Durakbaşa	TU Wien, Austria
B. Durmuşoğlu	İstanbul Technical University, Turkey
A. Erkollar	Sakarya University, Turkey
S. Erol	Gazi University, Turkey
Ş. Esnaf	İstanbul University, Turkey
S. Firat	Marmara University, Turkey
W. Fisher	University of California, Berkeley, USA
G. Gençyılmaz	İstanbul Aydın University, Turkey
D. Gerhard	Ruhr-University Bochum, Germany
S. Gözlü	İstanbul Technical University, Turkey
S. Grozav	Technical University of Cluj Napoca, Romania
K. Gülen	Namık Kemal University, Turkey
A. Güngör	Pamukkale University, Turkey
E. Hekelová	City University Bratislava, Slovakia

A. Sorguç	Middle East Technical University, Turkey
H. Soyuer	Ege University, Turkey
K. Stepien	Kielce University of Technology, Poland
P. Tamas	Budapest University of Technology and Economics
B. Tan	Koç University, Turkey
M. Tanyaş	Maltepe University, Turkey
F. Taşgetiren	Yaşar University, Turkey
H. Taşkin	Sakarya University, Turkey
M. Tekin	Selçuk University, Turkey
A. Toraman	İstanbul Technical University, Turkey
J. Torgersen	Norwegian University of Science and Technology, Norway
O. Torkul	Sakarya University, Turkey
G. Ulusoy	Sabancı University, Turkey
G. Varga	University of Miskolc, Hungary
K. Velíšek	Slovak University of Technology, Slovakia
J. Wang	National University of Singapore
A. Weckenmann	University of Erlangen Nürnberg, Germany
M. Yalçintaş	İstanbul Commerce University, Turkey
M. Yenisey	İstanbul University, Turkey
M. E. Yurci	Yıldız Technical University, Turkey
S. Zaim	İstanbul Zaim University, Turkey
W. Zebala	Cracow University of Technology, Poland
M. Zerenler	Selçuk University, Turkey

Reviewers

Akdogan, A.
Aktin, T.
Baray, Ş.
Bauer, J.
Berto, F.
Beyca, Ö.
Börühan, G.
Blecha, P.
Budak, I.
Bulut, Ö.
Büyüksaatçi, S.
Camgöz-Akdağ, H.
Crisan, L.
Çebi, F.
Demircioğlu, P.
Dragomir, M.
Dregelyi-Kiss, A.
Durakbasa, N.
Ekinci, E.
Erkollar, A.
Ersoy, P.
Esnaf, Ş.
Gençyılmaz, G.
Gergin, Z.
Gökçe, M.
Grozav, S.
Gülen, K.
Kabadurmuş, Ö.
Kandiller, L.
Kazançoğlu, Y.
Kopacek, P.
Králik, M.
Kräuter, L.
Majstrovic, V.

Maňková, I.
Mullaoğlu, G.
Novák, M.
Öner, A.
Öner, E.
Özgür, A.
Özkan, S.
Öztop, H.
Öztürkoğlu, Y.
Öztürkoğlu, Ö.
Paldrak, M.
Pokusová, M.
Soyuer, H.
Staiou, E.
Torgersen, J.
Tunçbilek, N.
Üney-Yüksektepe, F.
Varga, G.
Yetkin, B.
Zaim, S.
Zebala, W.

Contents

Big Data and Analytics

A Hybrid Recommender System: Uniqueness of Choices by Using Machine Learning Technique 3
Sanjeev Kumar, Ashirbad Sarangi, and R. P. Mohanty

IoT Based Real-World Emission Analysis of Motorcycles 14
Ernst Pucher, Andreas Gruber, and Christian Spitzwieser

Decision Making

Using Best Worst Method for Location Selection of Piezoelectric Tiles 27
Ali Sarper Özer, Heliya Hasani, Elif Bahar Genç, Nilsu Kutlu, Gül Tekin Temur, and Çağlar Sivri

Facility and Capacity Management

Site Selection for a Training Centre Focused on Industry 4.0 by Using DEMATEL and COPRAS 37
Semra Birgün and Mesut Ulu

Fuzzy Logic

Facility Location for Unmanned Aerial Vehicle Base Stations to Provide Uninterrupted Mobile Communication After Earthquakes 53
Gamze Sevdik, Sakir Esnaf, and Engin Baytürk

Healthcare Systems and Management

A Guide Application in Case of Emergency Health: A Case of Turkey 65
Hatice Camgöz Akdağ, Selin Şişmanoğlu, Süleyman Çoban, Tuğçe Beldek, and Aziz Kemal Konyalıoğlu

Parametric Design and Modeling of 3D Printed Prosthetic Finger 80
Yunus Emre Kahraman, Mert Madan, Binnur Sağbaş, and Numan M. Durakbasa

Industrial Applications

Conceptual Design and Fluid Structure Interaction Analysis of a Solar Powered High-Altitude Pseudo-Satellite (HAPS) UAV Wing Model 93
Mohammad Sakib Hasan, Jelena Svorcan, Dragoljub Tanovic, Gökçen Baş, and Numan M. Durakbasa

Design and Development of Drum Granulator 106
Ozge Tufan, Pınar Demircioğlu, İsmail Böğrekçi, and Utku Köse

Forecasting Electricity Generation and Shares by Energy Resources by Time Series Analysis: A Case-Study of Turkey 115
Aziz Kemal Konyalıoğlu and Nuri Çelik

Fused Filament Fabrication of Ceramic Components for Home Use . . . 121
Günther Poszvek, Clemens Wiedermann, Erich Markl, Jorge M. Bauer, Rolf Seemann, Numan M. Durakbasa, and Maximilian Lackner

Fused Filament Fabrication of Metallic Components for Semi-professional and Home Use 140
Günther Poszvek, Gerald Stattler, Erich Markl, Rolf Seemann, and Maximilian Lackner

Increasing of Stud Welding Efficiency in the Body Shop 150
Marian Králik and Vladimír Jerz

Measurements of a Finished Garment Using 3D Laser Image Processing 162
Semih Dönmezer

Porosity Measurement by X – Ray Computed Tomography: Different Porosity Analysis Application 175
Michaela Kritikos

Industrial Robotics in Production Systems and Industrial Engineering

Accuracy Improvement and Process Flow Adaption for Robot Machining . . . 189
Martin Kainrath, Mohamed Aburaia, Kemajl Stuja, Maximilian Lackner, and Erich Markl

Artificial Neural Networks Based Place Categorization . . . 201
Andreas Kriegler, Wilfried Wöber, and Mohamed Aburaia

Logic Control of an Industrial Automation Cell with ROS as Part of SMEs and Industry 4.0 Interconnection . . . 210
Erich Markl, Jorge M. Bauer, David Riepl, and Thomas Steiner

Robot Retrofitting by Using LinuxCNC Complemented with Arduino/RaspberryPI . . . 222
Peter Kopacek, Jorge M. Bauer, Miguel Llaja, Santiago Fauda, Jorge M. Acosta, Rodrigo Algoberro, and Félix Cuello

Parameter Optimization for the 3D Print of Thermo-Plastic Pellets with an Industrial Robot . . . 236
Stefan Otto Felber, Mohamed Aburaia, Wilfried Wöber, and Maximilian Lackner

Industry 4.0 Applications

A Comparative Sectoral Analysis of Industry 4.0 Readiness Levels of Turkish SMEs . . . 251
Oğuz Emir, Zeynep Gergin, Fadime Üney-Yüksektepe, Uğurcan Dündar, Güneş M. Gençyılmaz, and Ali Ihsan Çavdarlı

A Decision Support Tool for Classification of Turkish SMEs' Industry 4.0 Score Levels . . . 264
Uğurcan Dündar, Fadime Üney-Yüksektepe, Zeynep Gergin, Oğuz Emir, Güneş M. Gençyılmaz, and Ali İhsan Çavdarlı

Adaptation of CNC Machine Tools in Educational Center That Matches the Concept of Industry 4.0 . . . 277
Wojciech Zębala, Grzegorz Struzikiewicz, and Emilia Franczyk

Digital Maturity Assessment Model for Smart Agriculture . . . 289
Aysu Melis Büyük, Gizem Ateş, Salim Burghli, Deniz Yılmaz, Gül Tekin Temur, and Çağlar Sivri

Do We Need Synchronization of the Human and Robotics to Make Industry 5.0 a Success Story? . . . 302
Mary Doyle Kent and Peter Kopacek

Evaluation of the Challenges of Companies in Industry 4.0 Transformation by GRA Method 312
Hilmi Yüksel, Gülper Basmacı, and Serkan Genç

Industry 4.0 in Educational Process 324
Jan Vetiska, Michal Holub, Petr Blecha, Frantisek Bradac, Jakub Brazina, Vaclav Stanek, Jiri Kroupa, and Zdenek Tuma

Industry 4.0 vs. Society 5.0 333
Leyla Polat and Alptekin Erkollar

Intelligent Design and Advanced Precision Metrology on the Geometrical Structure of Medical Needles Based on GPS and ISO Standards 346
Osman Bodur, Günther Poszvek, Eva Maria Walcher, Numan M. Durakbasa, and Jorge M. Bauer

Social and Ethical Aspects of Automation 363
Mary Doyle Kent and Peter Kopacek

Social Transformation - Industry 4.0 373
Uğur Sütlü and Fatma Serab Onursal

Strategic Model Proposal Related to IoT Applications in Disaster Management 383
Buket Karatop, Buşra Taşkan, and Cemalettin Kubat

Usage and Applications of the Swarm Robotics Concept at Industrial Level 389
Beritan Can and Şakir Esnaf

Information Management

Design of a Database Management System for Movie Recommendation Related to the History of Industrial Engineering for Courses 401
Damla Akın and Sakir Esnaf

Process Mining Research in Management Science and Engineering Fields: The Period of 2010–2019 413
Atik Kulakli and Semra Birgun

Lean Production

Waiting as Waste in Lean Production Processes 429
Viktor Molnar

Logistics Management

A Critical Review of Quality Function Deployment (QFD) Tool Through Logistics Centre Development Projects 441
Rıza Gürhan Korkut, Metin Çelik, and Süleyman Özkaynak

Two-Phase Fuzzy C-Means and Genetic Algorithm for Food Distribution 453
Engin Baytürk, Sakir Esnaf, and Tarik Kucukdeniz

Optimization

Modelling and Optimization of Dissimilar Welding Between 304L and HSLA-X70 Using Response Surface Methodology 463
Mohamed Farid Benlamnouar, Tahar Saadi, Nabil Bensaid, Mokrane Gousmine, Youssef Touggui, and Mustapha Temmar

Proposing a Pre-emptive Resource Constrained Project Scheduling Problem (PRCPSP) Model to Optimize Manpower and Project Delivery Time (A Case Study) 473
Arman Saeidi, Kamran Rezaie, Alireza Nazari, and Amir Hossein Ordibazar

Process Management

Improvements in Manufacturing Processes by Measurement and Evaluation Studies According to the Quality Management System Standard in Automotive Industry 483
Ali Mert Özcan, Anıl Akdoğan, and Numan M. Durakbasa

Improving Business Processes of Human Resources Departments in Turkish Technic Inc. 493
Hande Nur Şavlı, Havva Burke Barot, Mirace Bengü Yüksel, Rumeysa Ekşi, Bahadır Tunaboylu, and Selim Zaim

Improving Manufacturing Process of Mobile Recorder 504
Pınar Demircioğlu, İsmail Böğrekçi, Berk Sevinç, and Numan M. Durakbasa

Manufacturing Process Development for Thin Film Filaments as a New Product 513
Bahadır Tunaboylu, Biset Toprak, Ahmet Korhan Binark, Osman Öztürk, and Selim Zaim

Modelling of the High-Chromium Cast Iron Surface Roughness 523
Borislav Savković, Pavel Kovač, Branko Štrbac, Marcela Pokusova, and Nenad Kulundžić

Productivity and Performance Management

A System Dynamics Model for Long-Term Performance Monitoring of Projects Related to Oil Production in Iran 537
Fatemeh Masoudian and Kamran Rezaie

An SME Examination on the Effect of Transition to Automation Systems on Production Performance 546
Güzide Karakuş, Saliha Öztürk, and Ayşenur Güldoğan

Performance Evaluation in the Firms of Turkish Textile Sector 558
Aylin Duman Altan and Kemal Güven Gülen

Some Universities Performance Evaluation of Entrepreneurship and Innovation in Turkey with Multiple Criteria Decision Making Methods 569
Mehmet Karahan and Sariye Peşmen

Turkey and Some EU Countries' Economic Performance Analysis with Multi-criteria Decision Making Methods: Promethee GAIA Application 584
Mehmet Karahan, Fatma Çetintaş, and Merve Sinem Karahan

Warehouse Planning for Maximum Area Efficiency in the White Goods Sector 598
Gizem Berkdemir, Gizem Atak, and Ferhan Çebi

Quality Management

Geometric Tolerancing Analysis of Multi-material Components (MMCs) Obtained by Industrial X-Ray Computed Tomography 607
Mario Sokac, Zeljko Santosi, Djordje Vukelic, Marko Katic, Numan M. Durakbasa, and Igor Budak

Intelligent Test Automation for Improved Software Quality Assurance 614
Gamze Uğur-Tuncer, Can Davutoglu, and Numan M. Durakbasa

The Role of Product Perceived Quality in Building Customer Behavioral Loyalty Across Retail Channels 625
Florian Teleaba and Sorin Popescu

R&D and Technology Management

Innovation Efficiency in Automotive Industry: The Case of Turkey 643
Gizem Günay, Gökhan Aldemir, and Ferhan Çebi

Overview of Technology Commercialization Options in Romania 658
Diana Dragomir, Diana Pitic, Mihai Dragomir, and Daniela Popescu

Risk Analysis and Management

Physical Asset Risk Management: A Case Study from an Asset-Intensive Organization 667
Mohsen Aghabegloo, Kamran Rezaie, and S. Ali Torabi

Risk Analysis Application for a Medical Device Manufacturer 679
Ayşe İrem Pınar and Nükhet Tunçbilek

Scheduling

Hybrid Flowshop Scheduling Problem at DrPaste 693
Ece Nural, Ceren Sanisoğlu, Esennur Ermiş, Sinem Ünver, Zehra Gürçay, and Zehra Düzgit

Service System Management

Effect of Gamification Applications on Individual Performance: Air Transportation Application 711
Samet Elitok and Hür Bersam Bolat

Simulation and Modelling

A Brief General Industrial Virtual Reality Applications Overview Including a Simple Factory VR Simulation 723
Cem Yurci and Numan M. Durakbasa

Investigation of the Efficiency of Vibration-Assisted Nano-Grinding with Molecular Dynamics 736
Nikolaos E. Karkalos, Angelos P. Markopoulos, and János Kundrák

Supply Chain Management

A New Approach to Location Routing Problem: Capacitated Periodic Location Routing Problem with Inventory 751
Esra Yaşar Boz, Ahmet Reha Botsalı, and Tuba Ulusoy

Smart Manufacturing of Electric Vehicles 767
Büşra Alptekin, Bahadır Tunaboylu, Selim Zaim, and Pietro Perlo

Capstone Projects

A Multi-sided and Multi-model Assembly Line Balancing Problem 777
Seda Gemici, Emine Otuzbir, İrem Almila Koçyiğit, Sinem Pekelli, Fethi Tüzmen, Hande Öztop, and Levent Kandiller

A Parallel Machine Scheduling Problem for a Plastic Injection Company 790
Aytaç Ali Aslaner, Akdeniz Coşkun, Nur İlayda Tülemiş, Ece Özboyacı, Nil Ergün, Berk Bulut, Görkem Gülbent, Mert Paldrak, and Efthymia Staiou

A Single Machine Job Scheduling Problem with Sequence Dependent Setup Times 804
Aylin Elibol, Selen Tosun, Emin Erbay, Egemen Orta, Öykü Gökşen, Asena Ceritoğlu, Çınar Arabacı, Hande Öztop, and Mustafa Arslan Örnek

An Implementation of Flexible Job Shop Scheduling Problem in a Metal Processing Company 817
Ali Ozan Özkul, Gamze Küçük, Ceren Çelik, Nevzatcem Öztuna, Mert Demirkan, Ezgi Çağlar Nizam, Yıldırımşan Büyükmertoğlu, Damla Yüksel, and Ayhan Özgür Toy

Analysis and Improvement of Employee Transportation System 831
Gökçe Fatma Akpinar, Merve Özdemir, Orhan Ege San, Emre Ege Ak, Oğuz Kaan Yalabik, Zafer Çağlar, Mert Paldrak, and Adalet Öner

Container Demand Forecasting Using Machine Learning Methods: A Real Case Study from Turkey 842
Ayhan Darendeli, Aylin Alparslan, Mehmet Serdar Erdoğan, and Özgür Kabadurmuş

Customer Order Scheduling in Hybrid Flow Shop Manufacturing System 853
Eylül Kacar, Esra Karakoç, İrem Kartop, Almira Öztürk, Görkem Bozkurt, Nazli Aygün, and Erdinç Öner

Development of Hydraulic Drive Railway Bearings Installation System 866
Pınar Demircioğlu, İsmail Böğrekçi, and Mehmet Temel

Improving the Operations in a Logistics Company: A Case Study in Turkey 876
Pınar Karaoglu, Tulin Mert, Muhammet Berkay Kork, Fevzi Batuhan Türkmen, Yeşim Deniz Özkan-Özen, and Yücel Öztürkoğlu

Improving the Throughput of Pipe and Tube Production: A Case Study 888
Aysu Aslaner, Aysu Gürokur, Enes Turan, Karya Varol, Melisa Menemenlioğlu, Ömer Faruk Çorum, Yağmur Aydoğan, Nazlı Karataş Aygün, and Erdinç Öner

Integrated Transportation and Packaging Problem Modeling and Application 900
Tuğçe Köksal, Ege Akkuş, Gökçe Demirel, Esin Tosun, Mahmut Ali Gökçe, and Cansu Yurtseven

Lean Warehouse Application in a Meat Producer Company 914
Aysu Aksütoğlu, Egemen Bıkmaz, Nazlı Ecem Sırkıntı, Melisa Özbiltekin Pala, and Esra Ekinci

Location Optimization of Receivers for IoT- Based Infrastructures 930
İlkay Gülbay, Hasine Acap, Ayşem Ayözen, Gözde Yücel, Eda Sönmez, Çiğdem Çelik, Mine Demir, Mert Paldrak, and Orkun Karabaşoğlu

Makespan Minimization in Manufacturing Process of a Company 943
Birkan Kayi, Halime Keçibaş, Aziz Kemal Konyalıoğlu, and Ferhan Çebi

Multi Model Multiple Line Balancing Problem Modeling and Real-Life Application 951
Onur Orhan, Doğukan Başgöl, Muharrem Eren Tekin, Ahmet Gülseven, Mahmut Ali Gökçe, Evren Demir, and Cansu Yurtseven

Quantitative Analysis of Stakeholder Perspective on the University-Industry-Government Collaboration in İzmir, Turkey 963
İnanç Kabasakal, Fatma Demircan Keskin, Yunus Kaymaz, Haluk Soyuer, Ahmet Rıza Balım, and Engin Eryılmaz

Parcel Delivery Service Quality Assessment 975
Belgin Aldatmaz, Candan Sever, Boran Pehriz, Aylin Çalışkan, and Burak Çetiner

Production Scheduling at a Powder Coating Company 989
Değer Demir, Ecem Ademoğlu, Gülce Gülen, Kerem Can Deliktaş, Mert Yandımata, Saadet Gül, Serdar Can Ertem, Önder Bulut, and Sinem Özkan

Ranking of Private Turkish Universities: Proposal of New Indicators 1002
Damla Kızılay and Murat Ödemiş

Author Index 1015

Manufacturing Process Development for Thin Film Filaments as a New Product

Bahadır Tunaboylu[1], Biset Toprak[2(✉)], Ahmet Korhan Binark[2], Osman Öztürk[3], and Selim Zaim[2]

[1] Marmara University, Istanbul, Turkey
bahadir.tunaboylu@marmara.edu.tr
[2] Istanbul Sabahattin Zaim University, Istanbul, Turkey
{biset.toprak,ahmet.binark,selim.zaim}@izu.edu.tr
[3] Gebze Technical University, Gebze, Kocaeli, Turkey
osmanozturk@gtu.edu.tr

Abstract. Thin films of rare-earth hexaborides are promising for wear and corrosion protective, decorative, and thermionic coatings. Among many hexaborides available, due to its unique properties lanthanum hexaboride (LaB_6) is used as a bright and long life thermionic electron source mostly in electron microscopes. Unlike single-crystal LaB_6 cathodes used today, LaB_6 thin-film coated metal filaments can be advantageous due to their simple design, easy installation, cost-efficient manufacturing, and less energy consumption. In the study, LaB_6 thin films were grown onto tantalum, molybdenum, and tungsten wire-substrates using magnetron sputtering. Tape-test was used on the film surface to determine the adhesion of the LaB_6 films to the substrates. The morphology, structure, and stoichiometry of tape-tested films were investigated by stereo microscopy, scanning electron microscopy (SEM) and X-ray photoelectron spectroscopy (XPS). Stereo microscopy and SEM analysis showed that the films were grown by magnetron sputtering have dense, fine columnar structure without peeling or flaking. In the XPS analysis of LaB_6/W film it was observed that the film was oxidized and there were no peaks of any element other than lanthanum, boron, and oxygen found. The analysis shows that the composition of the film was LaB_x coated over the tungsten (W) substrate at the deposition conditions.

Keywords: Thermionic coatings · Lanthanum hexaboride (LaB_6) thin film filament · Magnetron sputtering (MS) · Scanning electron microscope (SEM) · Transmission electron microscope (TEM)

1 Introduction

Among many hexaborides available, lanthanum hexaboride has been accepted as the best electron emitter due to the combination of high chemical stability, low evaporation rate at high temperature, and low work function [1–5]. After the investigation of electron emitter properties of lanthanum hexaboride by Lafferty [5], LaB_6 rod cathode was first designed by Broers [5, 6]. It was suggested that LaB_6 cathodes are superior to tungsten cathodes in terms of brightness, service life and mechanical stability [6, 7].

N. M. Durakbasa and M. G. Gençyılmaz (Eds.): ISPR 2020, LNME, pp. 513–522, 2021.
https://doi.org/10.1007/978-3-030-62784-3_44

Currently, LaB_6 and CeB_6 single-crystal cathodes are used in transmission electron microscopy (TEM), scanning electron microscopy (SEM), electron beam lithography, and X-Ray microanalysis, which offer high brightness and service life [1, 6, 8–10] Fig. 1 presents the commercially available tungsten and single-crystal LaB_6 cathodes. As can be seen from the figure, tungsten cathodes consist of hairpin filament when LaB_6 cathodes consist of hairpin filament as well as a single crystal tip. From Table 1, it can be noted that LaB_6 cathodes are superior to tungsten cathodes in terms of brightness and service life. Since operating temperature is one of the factors that affect service life, LaB_6 cathodes are preferable due to their lower operating temperature [11]. However, LaB_6 cathodes have a complicated design with various tip shapes (round, flat, sharp) and cone angles which increases the cost compared to tungsten cathodes. The cathodes are typically the main consumables in the electron microscopy operational costs. The tungsten, LaB_6 and CeB_6 cathodes are imported and their prices are 429 EUR (4.391 TL), 1.592 EUR (16.300 TL), and 4.600 EUR (47.111 TL), respectively. Turkey that has the largest boron resources in the world (73%) provides a motivation for development of high value-added boron products with innovative approach. For this purpose, LaB_6 thin-film coated metal filaments are investigated here in this application since they are promising due to their potential in simple design, easy usage, and low operating energy and low cost with respect to the single crystal cathodes [11–13]. In this study, we aimed to grow lanthanum hexaboride thin films on tantalum, molybdenum, and tungsten wires to develop a manufacturing process for thin-film filaments. In order to analyse the adhesion of the LaB_6 films to the substrates, tape-test was used on the film surfaces. Then, the morphology, structure, and stoichiometry of tape-tested films were investigated in terms of stereo microscopy, scanning electron microscopy, and X-ray photoelectron spectroscopy.

(a) (b)

Fig. 1. Image of commercially available (a) tungsten cathode and (b) LaB_6 cathode

Although LaB_6 thin film cathodes appeared to be advantageous when they are used as thin film-based products, the studies have mostly focused on electron emission

Table 1. Comparison of LaB_6 CeB_6 and tungsten cathodes [10, 14]

	LaB_6	CeB_6	Tungsten
Brightness (A/m^2-sr)	10^3	10^3	10^2
Typical service life (hr)	1000+	1500 +	30–100
Work function (eV)	2.70	2.65	4.5
Operating vacuum (torr)	10^{-7}	10^{-7}	10^{-5}
Operating Temperature (K)	1800	1800	2800
Current density at Operating Temperature (A/m^2)	20×10^{-4}–50×10^{-4}	20×10^{-4}–50×10^{-4}	3×10^{-4} (at 2800 K)
Evaporation rate (g/m^2-sec)	2.9×10^{-13}	2.1×10^{-13}	NA

properties of single crystal, pressed or sintered rod LaB_6 cathodes [5–7, 15–22]. In literature, lanthanum hexaboride thin films were grown by electrophoretic deposition [1, 11, 23], the evaporation [24], the magnetron sputtering [2, 3, 13, 25, 26], the electron beam deposition [27] and the pulsed laser deposition [8, 9, 28] in order to investigate their electron emission properties. Waldhauser found that among the rare earth elements, LaB_6 and CeB_6 are the most promising ones for utilization as coated cathodes but the highest electron emission was yielded from LaB_6 coated filament [26]. In addition, LaB_6 is very attractive for decorative hard coatings applied to luxury accessories due to its purple-red color spectrum and high hardness [12, 29, 30].

The first study to investigate the utilization of coated cathodes in electron microscopes was conducted by Khairnar and Mahajan [11]. In their study, LaB_6 was deposited on tantalum filament by electrophoretic deposition. The work functions were found between 2.6–2.8 eV. Before the deposition, the tantalum wire in hairpin shape was carburized to prevent diffusion of boron into the wire. It was found that LaB_6 coated tantalum filaments can be operated at 1873 K while uncoated tungsten filaments need a higher temperature than 3020 K at constant emission density. The lifetime of the filaments was found 55 h. Since the service life of the cathodes is affected by operating temperature, coated filaments were suggested. It was found that the service life of filaments is primarily determined by the adhesion of LaB_6 to the substrate.

However, the coatings produced by electrophoretic deposition were porous and poor in adhesion that results in fragile and undurable coating to thermal shocks. Besides, the preparation of that coatings is difficult because heat treatments are required before and after the deposition [13, 26].

Among the techniques mentioned above, the magnetron sputtering which is one of the physical vapor deposition (PVD) method, is used to deposit more dense, adhesive, and smoother films at low temperatures with ease of controlling the parameters [13, 31, 32]. The method is capable to produce thin films having the same functionality as thick films produced by other coating techniques [33–35]. In MS, the material called target, usually prepared by sintering or hot pressing, is deposited on the substrate as atomic-sized particles to form a thin film in a gaseous plasma [36].

Since the adhesion of the LaB_6 thin films is one of the main factors that affect service life, Mroczkowski used radio frequency (RF) magnetron sputtering to deposit adhesive LaB_6 thin films on tungsten. As a result, adherent, and stress-free thin films with 1µm thickness were obtained. Work function and electron emission values were found to be consistent with results obtained from bulk LaB_6. The lifetime measurements were carried out at 1200 K and measured as more than 1000 h. The work function of the films was between 2.4–2.6 eV. The surface of the films contained lanthanum oxide (La_2O_3) in addition to LaB_6 [13].

Kinbara et al. deposited LaB_6 films direct current magnetron sputtering (DCMS) on glass substrates to investigate the impact of argon pressure on the composition of the films. It was found that (100) plane films, which are preferred as electron emitters due to their low work function, can be obtained under 1 Pa argon pressure [26]. In the study conducted by Waldhauser et al., deposition parameters were optimized by using DCMS to coat the molybdenum and tungsten sheets. After determining the optimum parameters, the work function was found as 2.8 eV [3]. Waldhauser et al. growed LaB_6 thermionic coatings on molybdenum and tungsten substrates by MS. It was found that films were over stoichiometric. However, with increase in the argon pressure the ratio was approximated to stoichiometry [26]. Craciun et al. obtained boron deficiency, which may be caused by the mass difference between lanthanum and boron atoms [9]. It can be concluded that determining optimal coating parameters have a crucial impact on the morphology and structure of the films [37]. It was found that the service life of filaments is primarily determined by the adhesion of LaB_6 to the wire surface rather than the evaporation rate of lanthanum and boron [11]. Late et al. stated that good adhesion is required for durable electron emitters [28]. Thus, in this study, the adhesion of the LaB_6 films, which is deposited by MS determined using tape-test on the film surfaces. Then, the morphology, structure, and stoichiometry of tape-tested films were investigated in terms of stereo microscopy, scanning electron microscopy, and X-ray photoelectron spectroscopy.

2 Experimental Method

The films were sputtered on tungsten, molybdenum, and tantalum wire-based substrates by magnetron sputtering (MS) system existing in Gebze Technical University, Surface Physics Laboratory with using commercially available disc target composed of 99.9% LaB_6 (Diameter: 76 mm and Thickness: 10 mm). The MS system consists of BesTech deposition chamber with 6 Guns: 3 direct current (DC), 2 radio frequency (RF), and 1 DC-Pulse. In the study, the RF gun was used with 25 W to deposit the tungsten, molybdenum, and tantalum wires with a diameter of 1.1 mm, 1 mm and 0.7 mm, respectively and 1.2 mm long. Then, the substrates were subjected to the wire shaping process by cutting into two pieces transverse for obtaining a flat surface. After the wire shaping process, all substrates were placed into the holder (see Fig. 2) to form thin films under the same conditions simultaneously. Then the holder was placed into the magnetron sputtering system as the distance between the substrates and target material was 50 mm. Before the deposition, substrate surfaces were cleaned with 100 W in a vacuum environment to remove contaminations and oxides. The films were deposited directly, without using any intermediate layer, on the substrates that were kept at room temperature. Sputtering was carried out under the 2×10^{-3} mbar pressure and

20 W sputtering power with maintaining high purity argon at a flow rate of 3 sccm. Since we have 3-in. guns and the thickness verifying was controlled by Quartz Crystal Microbalance (QCM) in situ, also the deposition ratio of guns calibrated by using XPS. Therefore, the thickness of the films was well-controlled magnetron sputtering and deposition was continued until 2.5 nm thickness was obtained.

Fig. 2. Schematic illustration of the holder developed

3 Results

In order to analyse the adhesion of the LaB_6 films to the substrates, tape-test was applied on the film surfaces. Then, the morphology, structure and stoichiometry of tape-tested films were investigated in terms of stereo microscopy, SEM and XPS. The images obtained from the stereo microscopy are presented in Fig. 3. As shown in the figure below, there is no peeling or flaking observed after the tape test on the surface of the LaB_6 coated molybdenum, tantalum and tungsten samples.

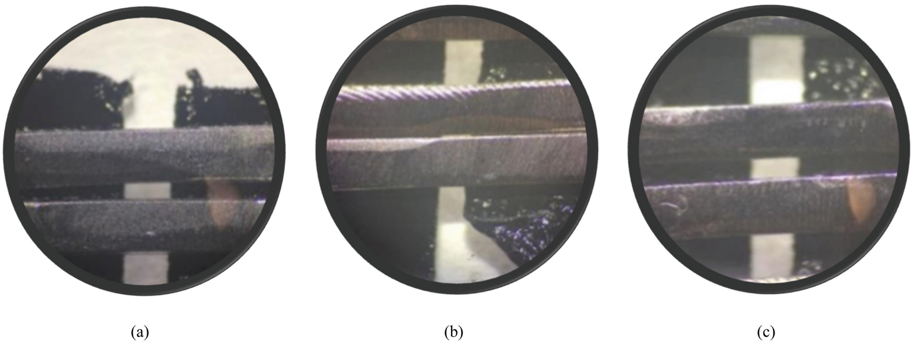
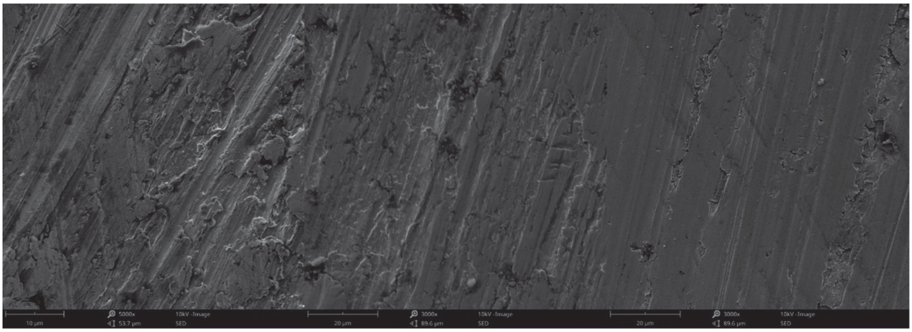


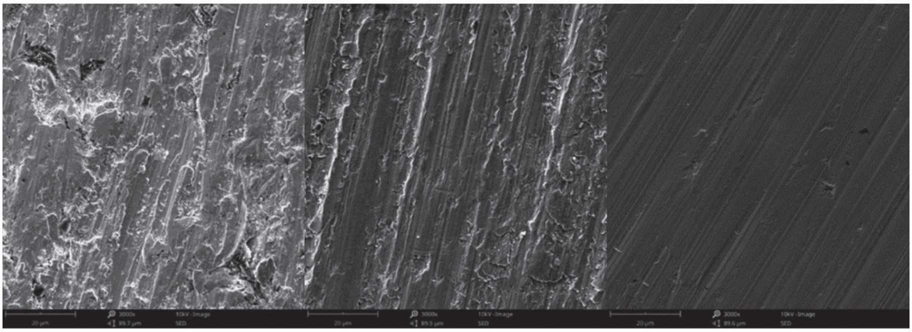
Fig. 3. Stereo microscopy image of tape tested LaB_6 on (a) molybdenum (b) tantalum and (c) tungsten with 45X magnification factor

The morphology of the films was analysed by Phenom XL scanning electron microscopy. Figure 4 presents scanning electron micrograph of uncoated molybdenum, tantalum and tungsten with 3000X magnification factor. From the figure, it is apparent that films of LaB_6/W is smoother than those of LaB_6/Mo and LaB_6/Ta. Since the



(a) (b) (c)

Fig. 4. Scanning electron micrograph of uncoated surface of (a) molybdenum, (b) tantalum and (c) tungsten with 3000X magnification factor



(a) (b) (c)

Fig. 5. Scanning electron micrograph of tape tested LaB_6 on (a) molybdenum, (b) tantalum and (c) tungsten with 3000X magnification factor

tungsten is the hardest among tantalum and molybdenum, this result is expected because of the wire shaping process. Figure 5 shows SEM image of LaB_6 film deposited onto molybdenum, tantalum and tungsten, respectively. Film growth seems to be dense and shows a fine-columnar structure. It can be noted from the SEM analysis films produced by magnetron sputtering are dense and strongly adhered to the wires that will be used as a filament. Since the adhesion depends on the substrate characteristics as well as film properties, good adhesion of the films was partly provided by the cleaning process done before deposition [31].

The surface composition and elemental ratios of the LaB_6/W film was determined by X-ray photoelectron spectroscopy measurements were performed by using SPECA Phoibos 150 specs charged particle analyzer (Charge analyzer: 9 MDC- charge detectors) including x-ray gun XR-50 (Anode:Al Kα- 350 W), which exist in GTU Surface Physics Laboratory. The attenuation depth was 6 nm for the XPS. It can be seen from the XPS scan in Fig. 6 the film was oxidized. No peaks of any element other than lanthanum, boron, and oxygen have been observed on the spectrum.

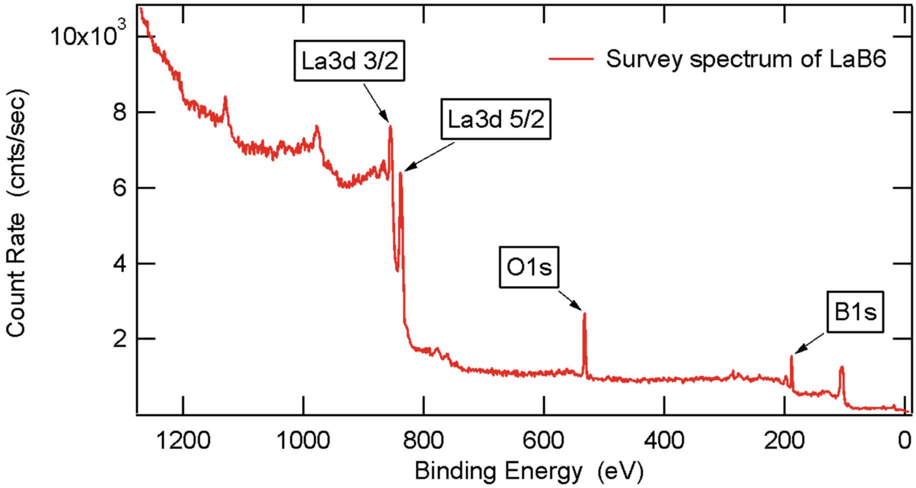


Fig. 6. X-ray photoelectron spectra of the LaB_6/W film

XPS was performed for survey and elemental windows to calculate elemental stoichiometry of the LaB_6/W film. The elemental ratios obtained from the XPS analysis are presented in Table 2. But the numbers on the table is taken from window scans of the elements. Also, we had three scans for one survey (with nine charge detectors), so it was enough for statistical calculation. From the X-ray photoelectron spectra, surface appearance of the LaB_6/W film was found to be LaB_x.

Table 2. Elemental ratio calculation of LaB_6 films

Peak Name	Peak Area (A)	ASF	A/ASF	%
O1s	1068.3	0.711	1502,53	28,55
B1s	482.8	0.159	3036,48	57,70
La3d	6602.9	9.122	723,84	13,75

4 Conclusion

The study aimed to perform the deposition of LaB_6 thin films on molybdenum, tantalum, and tungsten wires and investigation of their adhesion, morphology, and elemental ratio. In order to determine the adhesion of the LaB_6 films, tape-test was used on the film surfaces. Then, the morphology, structure, and stoichiometry of tape-tested films were investigated by stereo microscopy, SEM, and XPS. Stereo microscopy and SEM analyses showed that the films were grown by magnetron sputtering have dense and fine columnar structure without peeling or flaking. In the XPS analysis of LaB_6/W film, it was observed that the film was oxidized and there were no peaks of any element other than lanthanum, boron, and oxygen found. The analyses show that the composition of the film was LaB_x coated over W substrate at the deposition conditions. According to characterization results, the deposition and characterization of LaB_6 films on the metallic substrates were completed. These are encouraging results for the lower cost filament application. This study serves as a base of future studies for the domestic production of thin-film thermionic emitters with high quality and low price. However, further experiments are required to produce high-quality films in the desired composition by changing the target composition and magnetron sputtering system parameters. For further studies, LaB_6 target will be segmented to include a boron content to have stoichiometric films. After determining the optimal parameters, electron emission properties, and service life measurements of the samples will be investigated to develop a full manufacturing process for thin-film filaments for electron microscopes.

References

1. Buckingham, J.D.: Thermionic emission properties of a lanthanum hexaboride/rhenium cathode. Br. J. Appl. Phys. **16**, 1821–1832 (1965)
2. Nakano, T., Baba, S., Kobayashi, A., Kinbara, A., Kajiwara, T., Watanabe, W.: Structure modification of radio frequency sputtered LaB_6 thin films by internal stress. J. Vac. Sci. Technol. A **9**, 547–549 (1991)
3. Waldhauser, W., Mitterer, C., Laimer, J., Störi, H.: Structure and electron emission characteristics of sputtered lanthanum hexaboride films. Surf. Coat. Technol. **74–75**, 890–896 (1995)
4. Craciun, V., Cristea, D., Socol, G., Lambers, E., Trusca, R., Fairchild, S., Back, T., Gruen, G., Craciun, D.: Characteristics of LaB_6 thin films grown by pulsed laser deposition. J. Vac. Sci. Technol. A **34**, 547–549 (2016a)
5. Lafferty, J.M.: Boride cathodes. J. Appl. Phys. **22**, 299–309 (1951)
6. Broers, A.N.: Electron gun using long life lanthanum hexaboride cathode. J. Appl. Phys. **38**, 1991–1992 (1967)
7. Broers, A.N.: Some experimental and estimated characteristics of the lanthanum hexaboride rod cathode electron gun. J. Sci. Instrum. (J. Phys. E) **2**, 273–276 (1969)
8. Late, D.J., Date, K.S., More, M.A., Misra, P., Singh, B.N., Kukreja, L.M., Dharmadhikari, C.V., Joag, D.S.: Some aspects of pulsed laser deposited nanocrystalline LaB_6 film: atomic force microscopy, constant force current imaging and field emission investigations. Nanotechnology **19**, 1–6 (2008)
9. Craciun, V., Cristea, D., Socol, G., Lambers, E., Trusca, R., Fairchild, S., Back, T., Gruen, G., Craciun, D.: Characteristics of LaB_6 thin films grown by pulsed laser deposition. J. Vac. Sci. Technol. A Vac. Surf. Films **34**, 051509 (2016b)
10. https://www.emsdiasum.com/microscopy/products/brochures/Cathodes.pdf
11. Khairnar, R.S., Mahajan, P.W., Joag, D.S., Nigavekar, A.S., Kanitkar, P.L.: Processing and characterization of LaB_6 coated hairpin cathodes. J. Vac. Sci. Technol. A **3**, 398–402 (1985)
12. Mitterer, C.: Borides in thin film technology. J. Solid State Chem. **133**, 279–291 (1997)
13. Mroczkowski, S.J.: Electron Emission Characteristics of Sputtered Lanthanum Hexaboride. J. Vac. Sci. Technol. **9**, 586–590 (1991)

14. https://blog.phenom-world.com/thermionic-electron-sources-sem-filaments-emission-stability
15. Broers, A.N.: High resolution thermionic cathode scanning transmission electron microscope. Appl. Phys. Lett. **22**, 610–612 (1973)
16. Schmidt, P.H., Joy, D.C., Longinotti, L.D., Leamy, H.J., Ferris, S.D., Fisk, Z.: Anisotropy of thermionic electron emission values for LaB_6 single-crystal emitter cathodes. Appl. Phys. Lett. **29**, 7 (1976)
17. Schmidt, P.H., Longinotti, L.D., Joy, D.C., Ferris, S.D., Leamy, H.J., Fisk, Z.: Design and optimization of directly heated LaB_6 cathode assemblies for electron beam instruments. J. Vac. Sci. Technol. **15**, 1554–1560 (1978)
18. Swanson, L.W., Dickinson, T.: Single-crystal work-function and evaporation measurements of LaB_6. Appl. Phys. Lett. **28**, 578–580 (1976)
19. Oshima, C., Bannai, E., Tanaka, T., Kawai, S.: Thermionic work function of LaB_6 single crystals and their surfaces. J. Appl. Phys. **48**, 3925–3927 (1977)
20. Jacobson, D.L., Storms, E.K.: Work function measurement of lanthanum - boron compounds. IEEE Trans. Plasma Sci. **6**, 191–199 (1978)
21. Storms, E.K., Mueller, B.A.: A study of surface stoichiometry and thermionic emission using LaB_6. J. Appl. Phys. **50**, 3691–3698 (1979)
22. Goebel, D.M., Hirooka, Y., Sketchley, T.A.: Large-area lanthanum hexaboride electron emitter. Rev. Sci. Instrum. **56**, 1717–1722 (1985)
23. Favreau, L.J.: Cataphoretic coating lanthanum boride on rhenium filaments. Rev. Sci. Instrum. **36**, 856–857 (1965)
24. Oshima, C., Horiuchi, S., Kawai, S.: Thin film cathodes of lanthanum hexaboride (LaB_6). Jpn. J. Appl. Phys. **13**, 281–284 (1974)
25. Kinbara, A., Nakano, T., Kobayashi, A., Baba, S., Kajiwara, T.: LaB_x thin films prepared by magnetron sputtering. Appl. Surf. Sci. **70**(71), 742–745 (1993)
26. Waldhauser, W., Mitterer, C., Laimer, J., Stori, H.: Sputtered thermionic hexaboride coatings. Surf. Coat. Technol. **98**, 1315–1323 (1998)
27. Yutani, A., Kobayashi, A., Kinbara, A.: Work functions of thin LaB_6 films. Appl. Surf. Sci. **70**(71), 737–741 (1993)
28. Late, D.J., More, M.A., Sinha, S., Dasgupta, K., Misra, P., Singh, B.N., Kukreja, L.M., Bhoraskar, S.V., Joag, D.S.: Synthesis and characterization of LaB_6 thin films on tungsten, rhenium, silicon and other substrates and their investigations as field emitters. Appl. Phys. A **104**, 677–685 (2011)
29. Mitterer, C., Komenda-Stallmaier, J., Losbichler, P., Schmölz, P., Werner, W.S.M., Störi, H.: Sputter deposition of decorative boride coatings. Vacuum **46**, 1281–1294 (1995)
30. Mitterer, C., Komenda-Stallmaier, J., Losbichler, P., Schmölz, P., Störi, H.: Decorative boride coatings based on LaB_6. Surf. Coat. Technol. **74–75**, 1020–1027 (1995)
31. Baptista, A., Silva, F.J.G., Porteiro, J., Mígueza, J.L., Pintoa, G., Fernandes, L.: On the physical vapour deposition (PVD): evolution of magnetron sputtering processes for industrial applications. In: 28th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2018). Global Integration of Intelligent Manufacturing and Smart Industry for Good of Humanity, Columbus, OH, USA, 11–14 June 2018, pp. 746–757 (2018)
32. Swann, S.: Magnetron sputtering. Phys. Technol. **19**, 67–75 (1988)
33. Ray, A.K.: Hard nitride coatings by DC magnetron sputtering. Mater. Sci. Forum **246**, 61–90 (1997)
34. Constantin, D.G., Apreutesei, M., Arvinte, R., Marin, A., Andrei, O.C., Munteanu, D.: Magnetron sputtering technique used for coatings deposition; technologies and applications. Recent **12**(1), 29–33 (2011)

35. Abusuilik, S.B., Inoue, K.: Effects of intermediate surface treatments on corrosion resistance of cathodic arc PVD hard coatings. Surface Coatings Technology **237**, 421–428 (2013)
36. Pessoa, R.S., Fraga, M.A., Santos, L.V., Galva, N.K.A.M., Maciel, H.S., Massi, M.: Plasma-assisted techniques for growing hard nanostructured coatings: an overview. In: Anti-Abrasive Nanocoatings, pp. 455–479. Elsevier (2015)
37. Ivashchenko, V.I., Turchi, P.E.A., Shevchenko, V.I., Medukh, N.R., Leszczynski, J., Gorb, L.: Electronic, thermodynamics and mechanical properties of LaB_6 from first-principles. Phys. B Condens. Matter **531**, 216–222 (2018)