

UNIVERSITY OF BELGRADE  
TECHNICAL FACULTY BOR

**52<sup>nd</sup> International October Conference on  
Mining and Metallurgy**



**PROCEEDINGS**

Edited by

**Saša Stojadinović**

and

**Dejan Petrović**

**November 29<sup>th</sup> – 30<sup>th</sup> 2021**

**Bor, Serbia**

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on Mining and Metallurgy, IOC 2021**

PUBLISHER:

UNIVERSITY OF BELGRADE - TECHNICAL FACULTY IN BOR, BOR, NOVEMBER 2021

FOR THE PUBLISHER:

DEAN: Prof. dr Nada Štrbac

EDITORS:

Prof. dr Saša Stojadinović

Doc. dr Dejan Petrović

TECHNICAL EDITOR

Pavle Stojković, MSc.

PRINTED BY:

»Štamparija Atlantis d.o.o.« Niš

CIRCULATION: 100 Copies

CIP – Каталогизација у публикацији –

Народна библиотека Србије, Београд

622(082)

669(082)

**INTERNATIONAL October Conference on Mining  
and Metallurgy (52 ; 2021 ; Bor)**

Proceedings / 52nd International October  
Conference on Mining and Metallurgy - IOC 2021,  
November 29<sup>th</sup> - 30<sup>th</sup> 2021 Bor, Serbia ; [organizer]  
University of Belgrade, Technical Faculty in Bor ;  
[co-organizer Institute for Mining and Metallurgy  
Bor] ; edited by Saša Stojadinović and Dejan  
Petrović. - Bor : University of Belgrade, Technical  
Faculty, 2021 (Niš : Atlantis). - V, 228 str. : ilustr. ;  
25 cm

Tiraž 100. - Bibliografija uz svaki rad.

ISBN 978-86-6305-119-5

а) Рударство -- Зборници б) Металургија --  
Зборници

COBISS.SR-ID 52072201

**ORGANIZER:**

UNIVERSITY OF BELGRADE – TECHNICAL FACULTY IN BOR

**Co-ORGANIZER:**

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## TABLE OF CONTENTS

Aleksandra Milosavljević	
<b>THE COMPLEXITY OF SEM-EDS – WHAT AFFECTS THE QUALITY OF OBTAINED RESULTS?</b>	<b>1</b>
Zoran Karastojković, R Perić, M Srečković	
<b>LASER QUENCHING OF CUTTING TOOL STEELS - A REVIEW</b>	<b>5</b>
Slavica Miletić, D Bogdanović, E Požega	
<b>IMPACT OF EXTRAORDINARY SECURITY MEASURES TO EMPLOYEES DURING THE PANDEMIC COVID-9</b>	<b>15</b>
Daniela Grigorova, R Paunova	
<b>KINETIC STUDY OF SOLID-PHASE REDUCTION OF POLYGRADIENT IRON-CONTAINING MATERIAL</b>	<b>19</b>
Emina Požega, D Simonović, S Marjanović, M Jovanović, L Gomidželović, M Mitrović, Z Stanojević Šimšić	
<b>PART I: WHAT MAKES A GOOD THERMOELECTRIC</b>	<b>23</b>
Emina Požega, D Simonović, S Marjanović, M Jovanović, L Gomidželović, M Mitrović, S Miletić	
<b>PART II: WHAT MAKES A GOOD THERMOELECTRIC</b>	<b>27</b>
Dragan Manasijević, Lj Balanović, I Marković, M Gorgievski, U Stamenković, K Božinović, D Minić, M Premović	
<b>STUDY OF MICROSTRUCTURE AND THERMAL CONDUCTIVITY OF THE Ag–Bi–Sn ALLOYS</b>	<b>31</b>
Vladimir S. Topalović, S Matijašević, S Grujić, J Stojanović, J Nikolić, V Savić, S Zildžović	
<b>THE INFLUENCE OF THE PARTICLE SIZE ON CRYSTALLIZATION OF GLASS POWDERS FROM THE SYSTEM <math>\text{Li}_2\text{O}-\text{Al}_2\text{O}_3-\text{GeO}_2-\text{P}_2\text{O}_5</math></b>	<b>35</b>
Vesna Marjanović, R Marković, V Krstić	
<b>TECHNOLOGIES FOR PHYSICAL TREATMENT OF WATER CONTAINING SELENIUM: A REVIEW</b>	<b>39</b>
Vesna Marjanović, R Marković, V Krstić	
<b>TECHNOLOGIES FOR BIOLOGICAL TREATMENT OF WATER CONTAINING SELENIUM: A REVIEW</b>	<b>43</b>
Milenko Jovanović, M Mikić, M Maksimović, D Kržanović, R Rajković, E Požega	
<b>USAGE SPECIFICS OF GEOGRIDS</b>	<b>47</b>

Srećko Manasijević, Z Zovko Brodarac, N Dolić, M Djurdjević, R Radiša	
<b>INTERMETALLIC BONDING BETWEEN A RING CARRIER AND AN ALUMINUM PISTON ALLOY</b>	<b>51</b>
Snežana Šarboh	
<b>PATENTED INVENTIONS OF LJUBOMIR KLERIĆ</b>	<b>55</b>
Miomir Mikic, M Jovanović, R Rajković, D Kržanović, E Požega	
<b>DEGRADED AREA OF VELIKI KRIVELJ QUARRY RECULTIVATION</b>	<b>59</b>
Dragana Adamović, D Ishiyama, H Kawaraya, O Yasumasa	
<b>EFFECTS OF TAILINGS ON GROUNDWATER ALONG BOR AND BELA RIVERS IN THE BOR MINING AREA, EASTERN SERBIA</b>	<b>63</b>
Ana Kostov, Z Stanojević Šimšić, A Milosavljević,	
<b>CHARACTERIZATION OF ALLOYS CuAlAu0.5</b>	<b>67</b>
Marija Milenković, V Jovanović, J Paunković, V Krstić	
<b>MULTICRITERIA ANALYSIS OF THE LEVEL OF SUSTAINABLE DEVELOPMENT OF THE TOPLICA DISTRICT USING THE ELECTRE METHOD</b>	<b>71</b>
Daniel Kržanović, R Rajković, D Stevanović, M Mikić, M Jovanović, S Petrović	
<b>LONG-TERM PLANNING OF MINING THE LEAD AND ZINC ORE DEPOSIT IN THE BRSKOVO ORE FIELD, THE REPUBLIC OF MONTENEGRO</b>	<b>75</b>
Radmilo Rajković, D Kržanović, M Mikić, M Jovanović	
<b>CALCULATION OF SAFETY DISTANCE FOR THE OPERATION OF MINING EQUIPMENT IN THE WORKING ENVIRONMENT WITH WEAKENED CHARACTERISTICS AT THE OPEN PIT "NORTH MINING DISTRICT" OF THE COPPER MINE MAJDANPEK</b>	<b>79</b>
Zdenka Stanojević Šimšić, A Kostov, A Milosavljević, E Požega	
<b>HARDNESS, MICROHARDNESS AND ELECTROCONDUCTIVITY OF ALLOYS WITH VARIABLE Cu CONTENT IN Cu-Al-Ag SYSTEM</b>	<b>83</b>
Miodrag Banješević	
<b>STRATIGRAPHY AND AGE OF ROCK UNITS AND MINERALIZATION IN THE TIMOK MAGMATIC COMPLEX AND THE BOR METALLOGENIC ZONE – A REVIEW</b>	<b>87</b>
Milan Radivojević, Z Stević, M Tanasković	
<b>DUALPHASED FOURWAY INTERSECTION REGULATED BY TRAFFIC LIGHTS WITH FIXED AND ADAPTIVE MOD OF OPERATION</b>	<b>93</b>
Filip Gramić, N Rančić, S Filipović, J Đorđević	
<b>USE OF COPPER TAILING AND COPPER SLAG IN 3D PRINTED CONCRETE PROCESSES</b>	<b>97</b>
Filip Gramić, N Rančić, S Filipović, J Đorđević,	
<b>POSSIBILITY OF USING MINING WASTE IN THE PRODUCTION OF BRICK PRODUCTS</b>	<b>101</b>

Stepan O. Vidysh

**GOLD-SILVER ALLOYS ANODIC DISSOLUTION RESEARCH IN HYDROCHLORIC ACID ELECTROLYTES** 105

Milan Gorgievski, M Marković, D Božić, Vr Stanković, N Štrbac, V Grekulović, M Zdravković

**ADSORPTION ISOTHERMS FOR COPPER IONS ADSORPTION ONTO WALNUT SHELLS** 109

Miljan Marković, M Gorgievski, N Štrbac, V Grekulović, A Mitovski, K Božinović, M Zdravković

**pH AND CONDUCTIVITY CHANGE DURING THE RINSING AND ADSORPTION OF COPPER IONS ONTO WALNUT SHELLS** 113

Vesna Grekulović, A Mitovski, M Rajčić Vujasinović, N Štrbac, M Zdravković, M Gorgievski, M Marković

**ELECTROCHEMICAL BEHAVIOR OF COPPER IN CHLORIDE MEDIUM IN THE PRESENCE OF WALNUT SHELL MACERATE** 117

Marija Šljivić-Ivanović, S Dimović, I Jelić,

**EXPERIMENTAL DESIGN APPROACH IN RADIONUCLIDE SORPTION** 121

Ivana Jelić, A Savić, M Šljivić-Ivanović, S Dimović

**INFLUENCE OF SILICA FUME ON SCC CONCRETE PROPERTIES** 125

Milan Radovanović, A Simonović, M Petrović Mihajlović, Ž Tasić, V Nedelkovski, M Antonijević

**L-LYSINE AS CORROSION INHIBITOR OF STAINLESS STEEL IN RINGER'S SOLUTION** 129

Dragana Marilović, M Trumić, M Trumić, Lj Andrić

**THE INFLUENCE OF CALCIUM IONS ON DEINKING FLOTATION RECOVERY UNDER DIFFERENT CONDITIONS** 133

Dragana Medić, S Milić, S Alagić, M Nujkić, S Đorđević, A Papludis

**OPTIMIZATION OF CATHODIC MATERIAL LEACHING PROCESS IN ACID-SULPHATE SOLUTION** 137

Milijana Mitrović, D Gusković, S Marjanović, B Trumić, E Požega, U Stamenković, J Petrović

**OBTAINING MULTILAYER COPPER STRIPS BY ARB (ACCUMULATIVE ROLL BONDING) ROLLING PROCESS** 141

Nataša Đorđević, S Mihajlović, N Obradović, A Peleš, S Filipović

**THE INFLUENCE OF HIGH COMPACTION PRESSURE ON CORDIERITE-BASED CERAMICS** 145

Nataša Đorđević, S Mihajlović, M Sokić, B Marković

**SEM AND X-RAY ANALYSES OF SINTERED MgO / Bi<sub>2</sub>O<sub>3</sub> BINARY SYSTEM** 149

Ivana Ilić, J Sokolović, M Trumić, Z Stirbanović

**COMPARATIVE RESULTS OF COPPER FLOTATION FROM SLAG BEFORE AND AFTER THE  
PROCESS OF MAGNETIC CONCENTRATION** 153

Daniela Grigorova

**FERROSILICON OBTAINING USING IRON-SILICATE –FAYALITE** 157

Slavica Mihajlović, M Jovanović, N Đorđević, A Patarić, M Vlahović, V Kašić

**THE CLAY PRELIMINARY TESTING FROM MUNICIPALITY AREA OF REKOVAC** 161

Milan Milosavljević, M Premović, D Minić, Dn Mansijević, Ar Đorđević, M Kolarević

**EXPERIMENTAL AND THERMODYNAMIC STUDY OF ISOTHERMAL SECTIONS AT 600 °C  
AND 400 °C OF TERNARY Bi-Cu-Ge SYSTEM** 165

Aleksandar Đorđević, D Minić, M Premović, D Mansijević, M Milosavljević, V Ristić

**STUDY OF TEMPERATURE PHASE TRANSFORMATION OF THE TERNARY Bi-Cu-Ge SYSTEM** 169

Aleksandar Savić, I Jelić, M Šljivić-Ivanović, S Dimović, N Pudar, A Pfandler

**RECYCLED COARSE AGGREGATE AND FLY ASH EFFECT ON COMPRESSIVE STRENGTH OF  
SELF-COMPACTING CONCRETE** 173

Vladan Kašić, D Životić, V Simić, A Radosavljević-Mihajlović, J Stojanović, S Mihajlović, M  
Vukadinović

**FORECAST RESOURCES OF ZEOLITHIC TUFFS OF SERBIA** 177

Vladan Kašić, A Radosavljević-Mihajlović, S Radosavljević, J Stojanović, S Mihajlović, M  
Vukadinović

**GEOLOGICAL AND MINERAL CHARACTERISTICS OF ZEOLITHIC TUFF TOPONICA DEPOSITS  
NEAR KOSOVSKA KAMENICA** 181

Konstantin Petkov, V Stefanova, P Iliev

**METHOD FOR UTILIZATION OF THE SULFURIC ACID OBTAINED DURING AUTOCLAVE  
DISSOLUTION OF PYRITE CONCENTRATE** 185

Stefan Đorđievski, D Ishiyama, Y Ogawa, Z Stevanović, O Osenyeng, D Adamović, V  
Trifunović

**MONITORING OF pH VALUE AND CONCENTRATION OF COPPER IN  
RIVERS DOWNSTREAM FROM BOR MINE IN PERIOD 2015-2021** 189

Viša Tasić, M Cocić, B Radović, T Apostolovski-Trujić

**CHEMICAL COMPOSITION OF PARTICULATE MATTER IN THE INDOOR AIR AT THE  
TECHNICAL FACULTY IN BOR (SERBIA)** 193

Snežana Ignjatović, I Vasiljević, M Negovanović

**DEFINING STRUCTURAL CORRELATION USING OF TOTAL HORIZONTAL GRADIENT** 197

Velizar Stanković, M Janošević

**INCREASING THE CAPACITY OF THE COPPER SMELTING COMPANY IN THE COMPANY  
"SERBIA ZIJIN COPPER" - CHALLENGES AND CONSEQUENCES TO THE ENVIRONMENT** 201

Vladimir Jovanović, D Todorović, B Ivošević, D Radulović, S Milićević, D Nišić

**CHARACTERIZATION OF PELLET SAMPLES OBTAINED BY PELETIZATION OF LIMESTONE  
AND SEAWEED** 205

Vanja Trifunović, L Avramović, R Jonović, S Milić, S Đorđievski, M Jonović

**HYDROMETALLURGICAL TREATMENT OF ELECTIRIC ARC FURNACE DUST IN AIM OF ZINC  
SEPARATION** 209

Jovana Bošnjaković, N Knežević, N Čutović, M Bugarčić, A Jovanović, Z Veličković, S  
Manasijević

**EVALUATION OF ADSORPTION PERFORMANCE OF PHOSPHATES REMOVAL USING CELL-  
MG HYBRID ADSORBENT** 213

Dragan Radulović, Lj Andrić, D Božović, V Jovanović, B Ivošević, D Todorović,

**POSSIBILITY OF USING LIMESTONE FROM "PJEŠIVAČKI DO"-DANILOVGRAD DEPOSIT AS  
FILLER IN VARIOUS INDUSTRY BRANCHES** 217

Predrag Stolić, J Ivaz, D Petrović, Zoran Stević

**ADVANTAGES OF MINING ENGINEERING CURRICULUM REALIZATION USING  
SOLUTIONS BASED ON FREE SOFTWARE** 221

Slađana Krstić, E Požega, S Petrović, S Magdalinović, D Urošević, S Miletić, Z Stojanović  
Šimšić

**QUALITY INVESTIGATION OF SAND FOR THE PRODUCTION OF AGGREGATES ON  
VINOGRADI LOCALITY (DELIBLATSKA PEŠČARA)** 225

Saša Marjanović, D Gusković, M Mitrović, E Požega ,B Trumić, U Stamenković

**INFLUENCE OF COLD ROLLING AND ANNEALING ON HARDNESS OF BIMETALLIC STRIP  
Cu– Al** 229

## PART II: WHAT MAKES A GOOD THERMOELECTRIC

Emina Požega<sup>1</sup>, Danijela Simonović<sup>1</sup>, Saša Marjanović<sup>2</sup>, Milenko Jovanović<sup>1</sup>, Lidija Gomidželović<sup>1</sup>, Milijana Mitrović<sup>2</sup>, Slavica Miletić<sup>1</sup>

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### Abstract

Successful synthesis of p type single crystal  $\text{Bi}_2\text{Te}_{2.8}\text{Se}_{0.2}$  by the Bridgman process obtained at the Serbian Academy of Sciences and Arts (SANU) in Belgrade was performed. A significant scientific contribution has been made in the application field of bismuth telluride as a thermoelectric material and selenium as its dopant. In this way, the conducted research enriched the set of data relevant for further research.

**Keywords:** Bridgman technique, Hall and Van der Pauw method, doping

### 1. INTRODUCTION

The best thermoelectric materials at temperatures from 300 K to 500 K [1,2,3] are  $\text{Bi}_2\text{Te}_3$ -based solid solutions, including  $(\text{Bi}, \text{Sb})_2\text{Te}_3$  and  $\text{Bi}_2(\text{Te}, \text{Se})_3$ .

The commercial  $\text{Bi}_2\text{Te}_3$ -based thermoelectric of p and n type are generally prepared by unidirectional solidification methods, such as zone melting [4], Bridgman [5,6], and Czochralski [7].

Good thermoelectric is defined as:

$$ZT = \frac{\alpha^2 \cdot \sigma \cdot T}{k} = \frac{\alpha^2 \cdot T}{k \cdot \rho} = \frac{\alpha^2 \cdot T}{(k_e + k_l) \cdot \rho} \quad (1)$$

where:  $\alpha$  - Seebeck coefficient,  $\sigma$  - electrical conductivity,  $k$  - thermal conductivity,  $T$  - absolute temperature,  $\rho$  - electrical resistance.

For almost all typical thermoelectric materials with doping increasing Seebeck coefficient is reduced. It is necessary large Seebeck coefficient and small resistivity and thermal conductivity as seen from the equation 1.

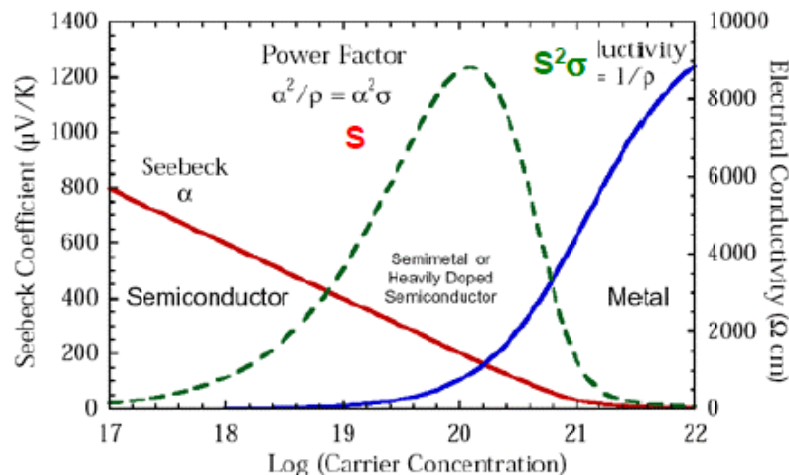


Figure 1. Materials with optimizing power factor[8]

Materials with good properties (Seebeck coefficient, electrical conductivity, thermal conductivity, electrical resistance, carrier concentration, power factor) and which can be good thermoelectric are present on the Figure 1.

Best compositions for traditional bulk thermoelectric materials had largely been discovered by 1980[9].

## 2. EXPERIMENTAL

A monocrystal sample of p - type,  $\text{Bi}_2\text{Te}_{2.8}\text{Se}_{0.2}$  was synthesized by the Bridgman method[10] at a temperature of  $600^\circ\text{C}$  starting from spectroscopic pure materials. Bismuth (Sigma - Aldrich, 99.999%), Selenium (Alfa Aesar, 99.999%) and Tellurium (Sigma - Aldrich, 99.999%) were taken in a certain proportion and sealed in a quartz ampoule under a pressure of  $10^{-5}$  Pa. According to the stoichiometry of  $\text{Bi}_2\text{T}_{3-x}\text{Se}_x$  ( $x=0.2$ ) alloy, high purity (5 N) elemental granules of Bi, Te and Se were weighed and then melted.

The lowering speed of the ampoule in the vertical furnace was about 2.2 mm/h. Structural, transport and thermoelectric properties were investigated. XRD analysis confirmed the monocrystal structure of  $\text{Bi}_2\text{Te}_{2.8}\text{Se}_{0.2}$ . Transport properties have shown that with increasing current, mobility increase. Positive values of Hall coefficient confirm that the material is p - type with high concentrations of charge carriers.

## 3. RESULTS AND DISCUSSION

The calculated data from the measurement results of the transport quantities for sample 6/4 ( $\perp$ ) with a Schottky diode at room temperature ( $25^\circ\text{C}$ ) and magnetic induction of the permanent magnet  $B = 0.370\text{ T}$  are given in Table 1 and Table 2. Measurements were performed at currents of 1 and 5 mA.

Table 1. Results for sample 6/4( $\perp$ ) at a current of 1 mA

Measured size	Symbol	Result	Measurement unit
Bulk carrier concentration	$n_b$	$4.876 \times 10^{19}$	$/\text{cm}^3$
Mobility	$\mu$	$1.700 \times 10^1$	$\text{cm}^2/\text{Vs}$
Specific resistivity	$\rho$	$7.529 \times 10^{-3}$	$\Omega\text{cm}$
Average Hall Coefficient	$R_H$	$1.280 \times 10^{-1}$	$\text{cm}^3/\text{C}$
A-C Cross Hall Coefficient	$R_{H1}$	$-4.388 \times 10^{-1}$	$\text{cm}^3/\text{C}$
B-D Cross Hall Coefficient	$R_{H2}$	$6.948 \times 10^{-1}$	$\text{cm}^3/\text{C}$
Sheet carrier concentration	$n_s$	$8.777 \times 10^{18}$	$/\text{cm}^2$
Specific conductivity	$\sigma$	$1.328 \times 10^2$	$1/\Omega\text{cm}$
Magneto resistance	$\Delta R$	$2.123 \times 10^{-3}$	$\Omega$
Vertical/Horizontal ratio of resistivity	$\alpha$	$9.643 \times 10^{-2}$	

Table 2. Results for sample 6/4(⊥) at a current of 5 mA

Measured size	Symbol	Result	Measurement unit
Bulk concentration	$n_b$	$6.640 \times 10^{18}$	/cm <sup>3</sup>
Mobility	$\mu$	$1.565 \times 10^2$	cm <sup>2</sup> /Vs
Specific resistivity	$\rho$	$6.008 \times 10^{-3}$	$\Omega$ cm
Average Hall Coefficient	$R_H$	$9.401 \times 10^{-1}$	cm <sup>3</sup> /C
A-C Cross Hall Coefficient	$R_{H1}$	$9.863 \times 10^{-1}$	cm <sup>3</sup> /C
B-D Cross Hall Coefficient	$R_{H2}$	$8.940 \times 10^{-1}$	cm <sup>3</sup> /C
Sheet concentration	$n_s$	$1.195 \times 10^{18}$	/cm <sup>2</sup>
Specific conductivity	$\sigma$	$1.664 \times 10^2$	1/ $\Omega$ cm
Magneto resistance	$\Delta R$	$2.442 \times 10^{-3}$	$\Omega$
Vertical/Horizontal ratio of resistivity	$\alpha$	$8.606 \times 10^{-2}$	

Mobility increases with increasing current. The Hall coefficient values are positive. This indicates that the samples are of p type and that the charge carriers majority are holes. That the samples are of p type was also confirmed by the hot point method. The mobility of most charge carriers decreases with increasing current, which indicates that the temperature of the samples increases, which affects on the mobility. For our sample the value of  $\mu$  is increase from  $\mu = 1.700 \times 10^1$  cm<sup>2</sup>/Vs at current intensity of 1 mA to  $\mu = 1.565 \times 10^2$  cm<sup>2</sup>/Vs at current intensity of 5 mA.

#### 4. CONCLUSION

Transport properties namely electrical conductivity ( $\sigma$ ), Hall Effect (RH), bulk carrier concentration ( $n_b$ ), sheet carrier concentration ( $n_s$ ), mobility ( $\mu$ ) and specific resistivity ( $\rho$ ) have been measured for the ternary system Bi<sub>2</sub>Te<sub>2.8</sub>Se<sub>0.2</sub> as function of current intensity.

RH measurement indicates p-type conduction. The results were analyzed in order to establish the conduction mechanism in these compounds. The aim of our researches is to characterize transport properties and to detect the possibility of using these materials in thermoelectric devices.

#### ACKNOWLEDGEMENTS

*Authors wish to thank Professor Academician Pantelija Nikolić<sup>†</sup> on big and selfless efforts and assistance in all stages of investigations. As well authors wish to thank Stevan Vujatović<sup>†</sup>, a specialized technician as well as Dr Ljiljana Živanović<sup>†</sup> full professor at the Department of Electronics, Department of Energy, Electronics and Telecommunications from the Faculty of Technical Sciences (FTN), University of Novi Sad and professor Dr Milan Radovanović, research associate, to help with the Hall experiment.*

*This work was financially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia, Grant No. 451-03-9/2021-14/ 200052.*

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**ISBN 978-86-6305-119-5**