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Bezusov A.T., Choporov O.N., Danylina H.V., Guido M., Kukhar V.V.et al.

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Authors:
Anishchenko O.S. (3), Barysheva Y.O. (2), Benedikt S. (4), Bezusov A.T. (2), Choporov O.N. (9), Danylina H.V. (1), Datsenko S.Y. (1), Fedoriv M.Y. (5), Galushchak I.D. (5), Guido M. (4), Klimov E.S. (3), Koenig E. (4), Kravchuk I.N. (1), Kukhar V.V. (3), Kurpe O.H. (3), Lvovich I.Y. (9), Lvovich Y.E. (8), Malinovskiy Y.A. (1), Manoli T.A. (2), Matsiyevska O. (11), Nikitchina T.I. (2), Osadchuk A.V. (4), Osadchuk I.A. (4), Pahomov R. (6), Peretiaka N.A. (2), Podchashinskiy Y.A. (10), Preobrazhenskiy A.P. (8, 9), Preobrazhenskiy Y.P. (8), Prysiazhnyi A.H. (3), Redkin O. (6), Shavurskaya L.Y. (10), Shavurskiy Y.A. (10), Skakalina E.V. (7), Tsvirkun S.L. (1), Uchitel A.D. (1), Vlasenkov D.P. (1), Zyma O. (6)

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site: www.sworld.education

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ÜBER DIE AUTOREN / ABOUT THE AUTHORS

1. *Anishchenko Oleksandr Serhiiovych*, Pryazovskyi State Technical University, Ukraine, Ukraine, PhD in technical sciences, assistant professor - *Chapter 3 (co-authored)*
2. *Barysheva Yana Olegovna*, Ukraine, graduate student, - *Chapter 2 (co-authored)*
3. *Benedikt Schulte,* Max Planck Institute for the Structure and Dynamics of Matter, Ukraine, applicant, - *Chapter 4 (co-authored)*
4. *Bezusov Anatoliy Timofeevich,* Odessa State Academy of Technical Regulation and Quality, Ukraine, Doctor of Technical Sciences, Professor - *Chapter 2 (co-authored)*
5. *Choporov Oleg Nikolaevich*, Voronezh State Technical University, Russia, Doctor of Technical Sciences, Professor - *Chapter 9 (co-authored)*
6. *Danylina Halyna Vladimirovna*, OSB "Kryvyi Rih Professional College of the National Aviation University, Ukraine, Doctor of Technical Sciences, assistant professor - *Chapter 1 (co-authored)*
7. *Datsenko Svetlana Yurievna,* OSB "Kryvyi Rih Professional College of the National Aviation University, Ukraine, - *Chapter 1 (co-authored)*
8. *Fedoriv Mykhaylo Yosypovysch,* Ivano-Frankivsk National Technical University of Oil and Gas, Ukraine, PhD in technical sciences, assistant professor - *Chapter 5 (co-authored)*
9. *Galushchak Ivan Dmytrovych,* Ivano-Frankivsk National Technical University of Oil and Gas, Ukraine, PhD in technical sciences, assistant professor - *Chapter 5 (co-authored)*
10. *Guido Meier,* Max Planck Institute for the Structure and Dynamics of Matter, Ukraine, Doctor of Technical Sciences, Professor - *Chapter 4 (co-authored)*
11. *Klimov Eduard Serhiiovych,* Kremenchuk Mykhailo Ostrohradskyi National University, Ukraine, PhD in technical sciences, assistant professor - *Chapter 3 (co-authored)*
12. *Koenig Elena,* Max Planck Institute for the Structure and Dynamics of Matter, Ukraine, PhD in technical sciences, senior researcher - *Chapter 4 (co-authored)*
13. *Kravchuk Igor Nikolaevich*, OSB "Kryvyi Rih Professional College of the National Aviation University, Ukraine, - *Chapter 1 (co-authored)*
14. *Kukhar Volodymyr Valentynovych,* Pryazovskyi State Technical University, Ukraine, Ukraine, Doctor of Technical Sciences, Professor - *Chapter 3 (co-authored)*
15. *Kurpe Oleksandr Hennadiiovych*, Pryazovskyi State Technical University, Ukraine, Ukraine, PhD in technical sciences, Senior Lecturer - *Chapter 3 (co-authored)*
16. *Lvovich Igor Yakovlevich*, Voronezh Institute of High Technologies, Russia, Doctor of Technical Sciences, Professor - *Chapter 9 (co-authored)*
17. *Lvovich Yakov Evseevich,* Voronezh State Technical University, Russia, Doctor of Technical Sciences, Professor - *Chapter 8 (co-authored)*
18. *Malinovskiy Yuriy Alexandrovich,* OSB "Kryvyi Rih Professional College of the National Aviation University, Ukraine, PhD in technical sciences, assistant professor - *Chapter 1 (co-authored)*
19. *Manoli Tatiana Anatolievna*, Ukraine, PhD in technical sciences, assistant professor - *Chapter 2 (co-authored)*

20. *Matsiyevska Oksana,* National University "Lviv Polytechnic", Ukraine, PhD in technical sciences, assistant professor - *Chapter 11*

21. *Nikitchina Tatiana Ivanovna,* Ukraine, PhD in technical sciences, assistant professor - *Chapter 2 (co-authored)*

22. *Osadchuk Alexander Vladimirovich,* Vinnytsia National Technical University, Ukraine, Doctor of Technical Sciences, Professor - *Chapter 4 (co-authored)*

23. *Osadchuk Iaroslav Alexandrovich*, Vinnytsia National Technical University, Ukraine, PhD in technical sciences, assistant professor - *Chapter 4 (co-authored)*

24. *Pahomov Roman*, National University "Poltava Polytechnic named after Yuri Kondratyuk", Ukraine, PhD in technical sciences, assistant professor - *Chapter 6 (co-authored)*

25. *Peretiaka Nataliia Aleksandrovna*, Ukraine, PhD in technical sciences, Senior Lecturer - *Chapter 2 (co-authored)*

26. *Podchashinskiy Yuriy Aleksandrovych,* Zhytomyr Polytechnic State University, Ukraine, Doctor of Technical Sciences, Professor - *Chapter 10 (co-authored)*

27. *Preobrazhenskiy Andrey Petrovich,* Voronezh Institute of High Technologies, Russia, Doctor of Technical Sciences, assistant professor - *Chapter 8 (co-authored), Chapter 9 (co-authored)*

28. *Preobrazhenskiy Yuriy Petrovich,* Voronezh Institute of High Technologies, Russia, PhD in technical sciences, assistant professor - *Chapter 8 (co-authored)*

29. *Prysiazhnyi Andrii Hryhoriiovych,* Pryazovskyi State Technical University, Ukraine, Ukraine, PhD in technical sciences, assistant professor - *Chapter 3 (co-authored)*

30. *Redkin Oleksandr,* National University "Poltava Polytechnic named after Yuri Kondratyuk", Ukraine, PhD in technical sciences, assistant professor - *Chapter 6 (co-authored)*

31. *Shavurskaya Liudmyla Yosyfovna,* Zhytomyr Polytechnic State University, Ukraine - *Chapter 10 (co-authored)*

32. *Shavurskiy Yuriy Aleksandrovych,* Zhytomyr Polytechnic State University, Ukraine, PhD in technical sciences, assistant professor - *Chapter 10 (co-authored)*

33. *Skakalina Elena Viktorovna,* National University "Yuri Kondratyuk Poltava Politechnics", Ukraine, PhD in technical sciences, assistant professor - *Chapter 7*

34. *Tsvirkun Sergij Leonidovich,* OSB "Kryvyi Rih Professional College of the National Aviation University, Ukraine, PhD in technical sciences, Senior Lecturer - *Chapter 1 (co-authored)*

35. *Uchitel Aleksandr Davydovich*, National Metallurgical Academy of Ukraine, Ukraine, Doctor of Technical Sciences, Professor - *Chapter 1 (co-authored)*

36. *Vlasenkov Dmitro Petrovich,* OSB "Kryvyi Rih Professional College of the National Aviation University, Ukraine, Senior Lecturer - *Chapter 1 (co-authored)*

37. *Zyma Oleksandr*, National University "Poltava Polytechnic named after Yuri Kondratyuk", Ukraine, PhD in technical sciences, assistant professor - *Chapter 6 (co-authored)*

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OPTIMIZATION OF TWO-LAYER RESISTS FOR LASER LITHOGRAPHY ON SUBSTRATES REQUIRED FOR WIDE APPLICATION IN MICROWAVE SENSOR TECHNOLOGY

ОПТИМИЗАЦИЯ ДВУХСЛОЙНЫХ РЕЗИСТОВ ДЛЯ ЛАЗЕРНОЙ ЛИТОГРАФИИ НА ПОДЛОЖКАХ, НЕОБХОДИМЫХ ДЛЯ ШИРОКОГО ПРИМЕНЕНИЯ В СЕНСОРНОЙ СВЧ ТЕХНИКЕ

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Introduction

We report on the optimization of laser lithography on various substrates relevant for ultra-high frequency on-chip experiments. We're aiming at fabricating microstructured photoconductive switches for transport experiments with sub-picosecond time resolution. Double layer resist systems for optimal lift-off processing of metal and semiconductor thin films are used. The double layer consist of LOR 3B as under layer and ma-P 1205 as top layer. Substrates are sapphire, i-GaAs, i-Si, SiO_2 on i-Si, and SiO_2 on p-doped Si. The target parameters for the optimization are the exposure dose and the edge roughness of microstructured elements. The latter is important to obtain high bandwidth striplines, microstrips, or coplanar waveguides.

The study of electronic transport properties of nanoscale systems on ultrashort time scales is a hot topic in solid state physics [1, 2]. There are several reasons for interest in such systems. First they comprise a variety of new physical phenomena [3-5]. Another reason is the possibility to manufacture a new generation of ultra-fast optoelectronic devices based on nanoscale systems [6, 7]. These devices includehigh-bandwidth striplines, microstrips, or coplanar waveguides [9, 10], as well as optical switches, such as photoconductive switches, also called Auston switches [8]. Also an interesting brunch of research in the field of terahertz are nano-devices with the properties of negative differential resistance [11, 12]. For the realization of ultra-fast electronic micro- and nanostructures and for nano-devices with negative differential resistance, the optimization of technological manufacturing methods as deposition, etching, and lift-off processes is very important. The purpose of this work is to improve the quality of resist masks used for lift-off processing under laboratory conditions to produce experimental nanostructures with dimensions down to 500 to 1000 nm, with controlled geometry and controlled boundary quality between different elements. In order to get a clean and reproducible lift-off, double-layer resists are utilized and adapted for our purposes. By using two different types of resist, one can precisely pattern the top photoresist and form an undercut in the photo insensitive bottom resist layer, resulting in a reliable lift-off profile. One should use resists with different solvents to avoid mixing of chemicals so that consistent results

across all sample batches are realized. Microchem PMGI/LOR and LOL [13] series resists work well as underlayer for i-line and broadband lithography, where the undercut rate is well controlled with standard developers [14, 15]. The uppermost layer can be a positive or negative photoresist and should typically not exceed one third of the total thickness. Especially positive photoresists as top layers are well suited for clean and repeatable lift-off processing [15]. In the present work resist of the ma-P 1200 series from microresist technology is used [16]. Optimizing the process requires an exposure series to determine the optimal exposure dose. This depends on the photoresist and the optical properties of the substrate and is described inter alia by the contrast curve [17]. The contrast of a photoresist is a measure of the sharpness of the transition from exposed to unexposed areas after the development process. Because the light spot is not perfectly binary, there will be grey areas where the resist is exposed by a fraction of the maximum dose. The higher the contrast of a photoresist, the less these grey areas are affected by the development process and the better the resolution of the resist system is. In this paper another parameter for the optimization of the resist process is considered, namely the edge roughness *R*. We find that this roughness critically depends on the exposure dose. The manufacturing process and the results of the optimization are described in detail in the following.

4.1. Experimental

The fabrication process of resist masks discussed here shall be used to manufacture photoconductive switches on various substrate materials that are relevant for ultrafast transport experiments. We study the properties of the double layer resist system for the following substrates: (a) sapphire from Pi-KEM Ltd., (b) intrinsic (low doped) gallium arsenide from Freiberger Compound Materials (i-GaAs), (c) intrinsic (low doped) silicon from Si-MAT GmbH (i-Si), (d) low-doped silicon with a thermally grown layer of silicon dioxide with a thickness 250 nm from Si-MAT GmbH (SiO_2 on Si), and (e) highly p-doped silicon with a thermally grown layer of silicon dioxide with thickness 285 nm from Nova Technology Inc. (SiO_2 on p-doped Si). Schematic images of all substrates and the double layer resist system with detailed parameters and geometries are shown in Fig. 1.

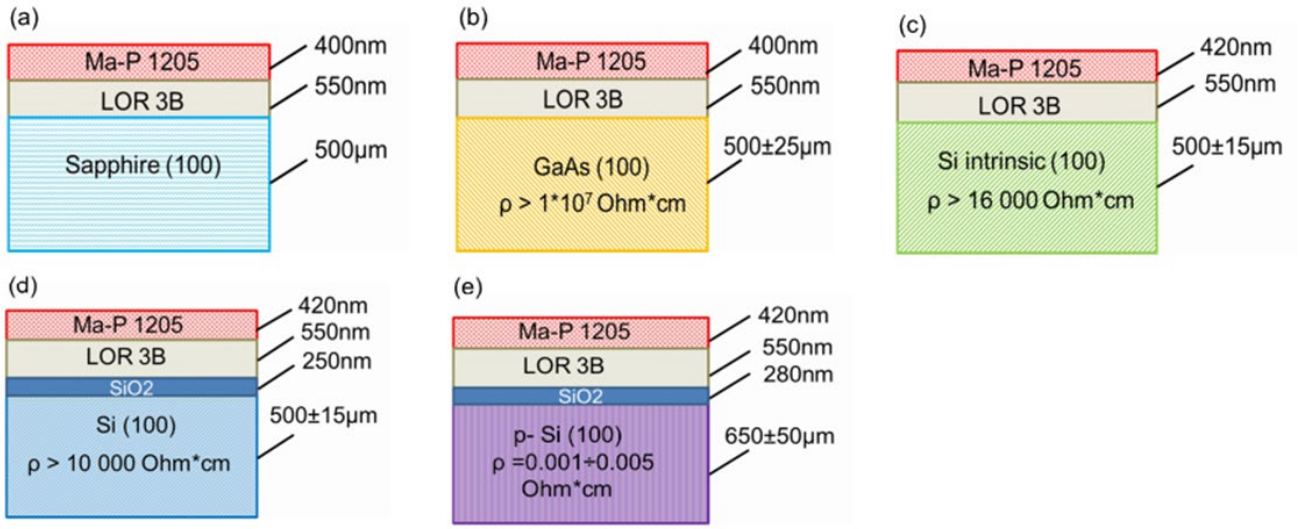

Figure1. Schematic representation of the substrates and double layer resist systems used in this study: (a) Sapphire, (b) i-GaAs, (c) i-Si, (d) SiO_2 on i-Si, and (e) SiO_2 on p-doped Si. Layer thicknesses and specific resistivity are denoted in this figure

4.2. Technology

4.2.1. Wet chemistry process and photoresist coating

The resists LOR 3B [13] and ma-P 1205 [16] are used, as this combination provides the required thickness, the undercut that is important for the later lift-off processing, as well as the sensitivity for the near UV (375 nm) laser beam of the lithography machine. All substrate types are cut into square pieces of 10 x 10 mm^2 using a laser prototyper LPKF ProtoLaser U3 [18], with the exception of the gallium arsenide wafers, that are cut with a diamond embedded in a custom build mechanical system for cutting wafers. After cutting, the substrates are cleaned with a standard method using acetone and isopropanol in an ultrasonic bath and washed in ultra-pure de-ionized water with a specific resistivity of 18.2 MΩ*cm [19] and dried with dry nitrogen with a purity of 99.999 %. The samples are heated to a temperature of 100 °C for 10 minutes on a hot plate to dehydrate the surface. Photoresists are applied by spin coating with a SPN150 Spin Coater [20]. First, an LOR 3B layer is spin coated on the substrate with 2000 rpm for 45 seconds. Then, the photoresist is baked on a hot plate at a temperature of 180°C for 4 minutes at an air temperature in the cleanroom at +22 °C ambient temperature and a humidity of 35 %. After slow cooling of the samples, a second photoresist of type ma-P 1205 is added by spincoating with 2000 rpm for 30 seconds. Then, the photoresist is baked on a hotplate at a temperature of 100 °C for 30 seconds in air at the abovementioned

temperature of air and humidity in the cleanroom.

4.2.2. Laser lithography

The double-layer resist is exposed in a laser lithography system µPG 101 from Heidelberg Instruments GmbH [23]. The µPG 101 uses a direct writing mode in near UV range, namely with a wavelength of 375 nm. To determine the contrast curves we expose arrays of rectangular elements with varying exposure dose. The initial values of the laser power and its intensity are 10 mW and 10 % while using a filter with 16 % transmission. The exposure intensity is increased in steps of 0.5 %. For the gallium arsenide substrate we increased the intensity in steps of 5%. This procedure leads to exposure doses ranging from 3 to 300 mJ/cm^2. For each intensity five 100 x 20 µm^2 rectangles are exposed on the various substrates. All samples are developed in the developer ma-D 331/S [13] for 60 s. Deionized water is used to stop the process. The samples are rinsed in propan-2-ol [24] and dried with dry nitrogen. The developing time is kept constant at 60 s.

4.2.3. Optical inspection and AFM measurements

The lateral quality of the double-layer resist on the substrate is checked with optical microscopy (Leica DM 3000) [21]. Then the roughness of the photoresist and the substrate as well as the thickness of each layer of the photoresist are measured by atomic-force microscopy (AFM) (Bruker, Icon Dimension) [22]. AFM measurements are performed with high resolution, low power, and asymmetric shape FESPA probes. For this type of probes we use the air tapping method in the soft tapping mode, which is most adequate for soft materials. Scanning is carried out both on the photoresist surface and on the surface of the substrate. The scanning region is chosen to be 50 × 50 µm^2. The AFM measurements show that the thickness of LOR 3B ranges from 500 to 550 nm, while the thickness of ma-P 1205 ranges from 450 to 490 nm. Depending on the properties of the various substrates, the total thickness of the double layer is found to range from 960 to 980 nm. To determine the contrast curves exposed with laser lithography we measured the height of the photoresist at the edge of a microstructure with a length of 50 µm or more. After characterization, a gold layer with a thickness of 200 nm is vapor deposited. In order to ensure better adhesion to the substrates, a titanium interlayer with a thickness between 6 and 10 nm is inserted. All deposition processes are performed in a vapor deposition system HVB 100 [25]. Finally, the lift-off process is carried out with remover mr-REM 700 [26]. Lift-off times varied depending on the substrate and ranged from 2 to 12 hours.

4.3. Results and discussion

4.3.1. Contrast curves

Figure 2 shows the contrast curve for each substrate for the double layer resist system LOR3B/ma-P 1205. In the contrast curve we plot the ratio of the resist layer remaining after development normalized to the original layer thickness as a function of the logarithmically scaled exposure dose as it is done conventionally [17]. The contrast γ is defined as

$$\gamma = \left(\log\left(\frac{D_C}{D_0} \right) \right)^{-1} , \quad (1)$$

where the so called dose-to-clear D_c is the dose at which after the development no photoresist remains on the substrate, while D_0 is the dose where the photoresist starts to develop.

Figure 2 shows the contrast curves and the concomittant fit functions versus exposure dose D for the five substrates. We obtain normalized thickness curves that follow a linear decay for all substrates. The dose-to-clear D_c has values between 70 and 160 mJ/cm^2 depending on the substrat material.

The calculated values for the contrast γ, the dose-to-clear D_c, and the dose where the photoresist starts to develop D_0 are listed in Table 1.

Table 1.

Exposure doses and contrast values for the five substrate materials.

Substrate	D_c (mJ/cm^2)	D_o (mJ/cm^2)	Contrast γ
Al_2O_3	110	41	2.3
i-GaAs	159	48	1.9
i-Si	102	37	2.3
SiO_2 on i-Si	103	46	2.9
SiO_2 on p-doped Si	68	35	3.5

The contrast values range from 1.9 to 3.5, which is the expected range for optical resists that typically provide contrast values from 0.4 to 4 [25].

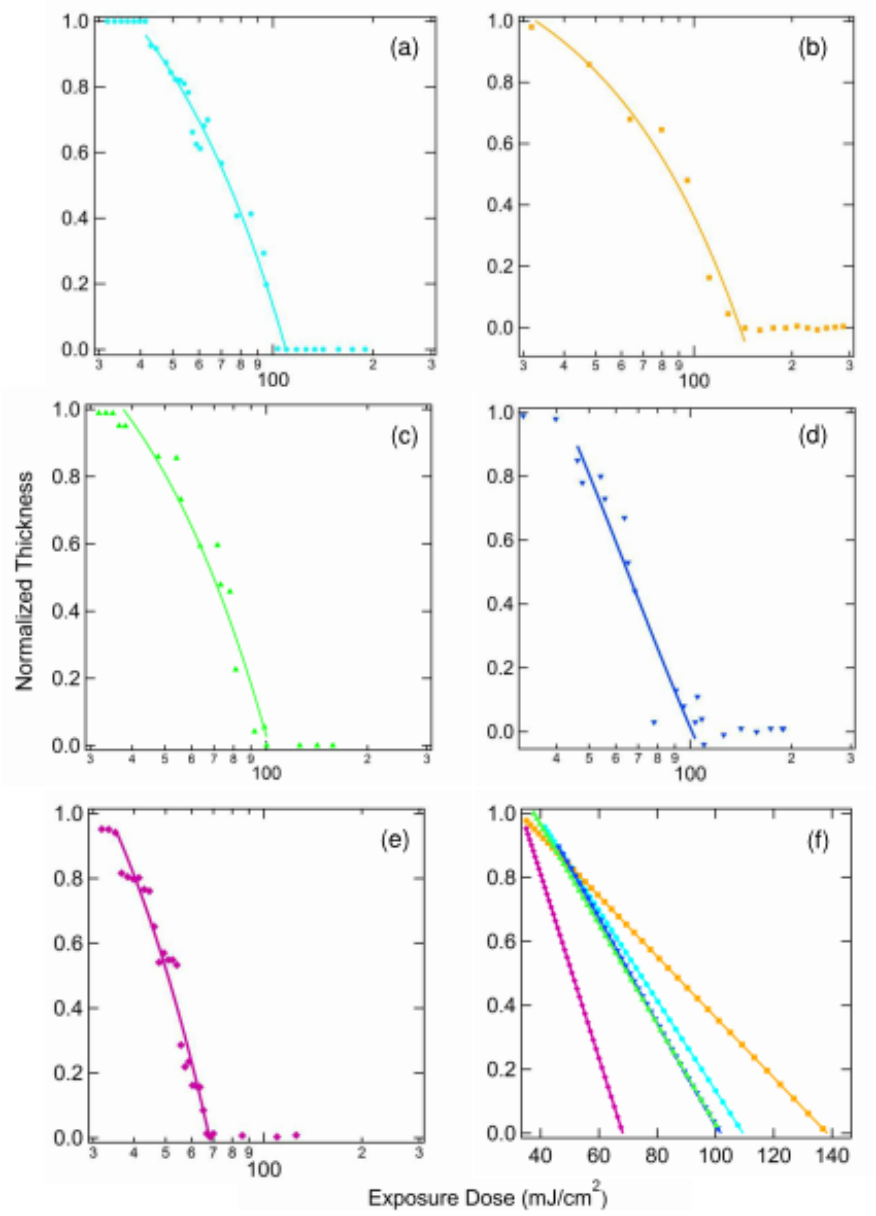

Figure 2. Contrast curves and concomitant fit curves for various substrates. (a) Sapphire, (b) i-GaAs, (c) i-Si, (d) SiO_2 on i-Si, and (e) SiO_2 on p-doped Si, (f) comparison of fit curves

4.3.2. Roughness of double layer resist

The roughness of the double layer resist system as well as of the substrate surfaces are measured with a Bruker Icon Dimension AFM using the roughness statistics software routine from Bruker. Statistics are derived following the standard B46.12 of the American Society of Mechanical Engineers ("Surface Texture: Surface Roughness, Waviness and Lay") [22]. After plane fitting the data we evaluate the root mean square and the arithmetic mean roughness values R_q and R_a. R_q is here defined as the standard deviation of the measured z_i values within the region of interest

$$R_q = \sqrt{\frac{\sum_{i=1}^{N} z_i^2}{N}}, \quad (2)$$

where N is the number of points within the region of interest. In our case the region of interest of 50 x 10 µm^{2}yielded $N \approx 50.000$. R_a is the arithmetic average of the absolute values of the measured z_i values within region interest

$$R_a = \frac{1}{N} \sum_{i=1}^{N} |z_i| \ . \quad (3)$$

Calculated roughnesses for the double-layer resist on all substrates for optimal dose are listed in Table 2.

Table 1.

Geometric and arithmetic roughnesses of photoresist and substrate.

Name of substrate	Roughness of photoresist (nm)		Roughness of substrate (nm)	
	R_q	R_a	R_q	R_a
Al_2O_3	7.8	3.9	11.3	6.3
i-GaAs	2.6	2.0	3.2	1.7
i-Si	2.7	1.5	6.4	4.1
SiO_2 on i-Si	3.9	3.0	7.9	6.4
SiO_2 on p-doped Si	5.4	2.3	8.6	3.0

The roughness values for all investigated substrates are in the range of 2 to 11 nm. The roughness of the substrates at the exposed sites is 2 to 4 nm larger than the roughness on top of the double-layer resist. After spin coating, soft baking and exposure the best roughness is found for the i-GaAs substrate. During the measurement of the contrast curves, it has been observed that the edge roughness changes strongly. It is reduced for increasing dose and then saturates. To elucidate this more we investigated the edge roughness systematically. The results are presented in the following.

4.3.3. Edge roughness of microstructured double-layer photoresist

Based on the software Igor from WaveMetrics [25] we determine the edge roughness of the microstructured double-layer resist on all five substrates. First, the position x_e of the edge is determined by fitting an error function to each line scanned vertical to the resist edge. After subtracting a linear fit to the edge positions the roughness R_e is calculated by the root mean square of the edge position values. For all samples the edge roughness is calculated for an edge length of at least 50 µm. All five microstructured elements of varying exposure dose are included in the calculation of

the edge roughness. Edge roughness values R_e, optimal exposure dose values from contrast curves D_c, and optimal exposure dose values from the study of the edge roughness D_e are listed in Table 3 and are shown in Figs. 3 and 4.

Table 3.

Comparison of edge roughness of microstructures, optimal dose from contrast curves, and optimal dose from edge roughness studies on various substrates.

Name of substrate	Edge roughness R_e (nm)	Optimal dose from contrast curve D_c (mJ/cm^2)	Optimal dose from edge roughness D_e (mJ/cm^2)	Contrast γ
Al_2O_3	35.8	110	110	2.3
i-GaAs	10.0	159	159	1.9
i-Si	15.4	102	102	2.3
SiO_2 on i-Si	20.2	103	110	2.9
SiO_2 on p-doped Si	24.2	68	78	3.5

The edge roughness is in the range of 10 to 36 nm for the optimum dose D_e depending on the substrate. Figure 3 shows the dependence of the optimal exposure dose D_c on the contrast for the five substrates. From the plot it can be inferred that a high contrast requires a low exposure dose [17].

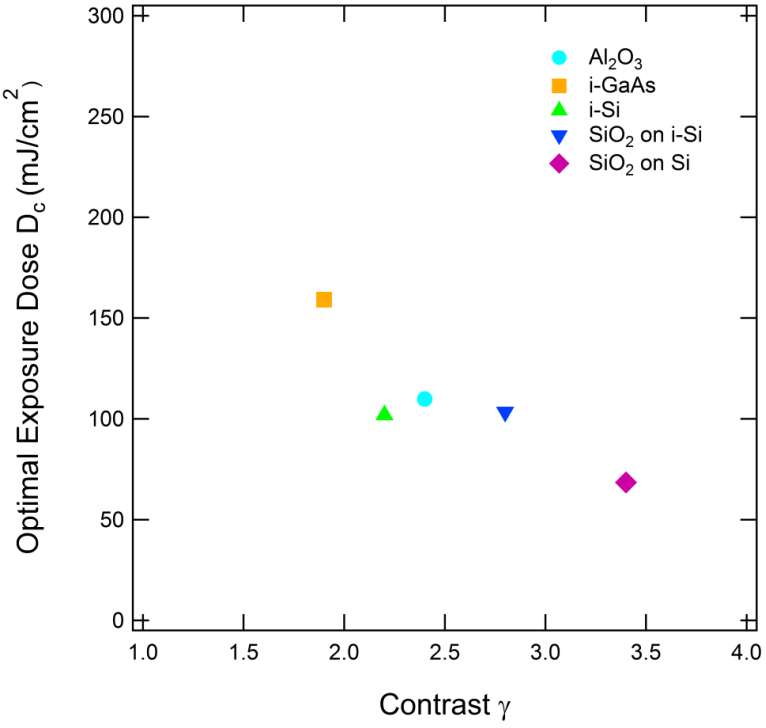

Figure 3. Dependence of the optimal exposure dose on the contrast for the five substrates

Figures 4 (a) and (b) show details of the AFM measurements in two different cases with either non-optimal and optimal dose, respectively. While Fig. 4 (a) shows the AFM image section in the case of low exposure dose yielding a rough edge, Fig. 4 (b) shows the AFM measurement for optimal exposure dose resulting in an optimal edge roughness.

Figure 4 (c) plots the edge roughness for each substrate as a function of exposure dose. Each point corresponds to an AFM measurement of the edge roughness at exposure doses between 60 mJ/cm^2 and 300 mJ/cm^2. The graph is plotted on a logarithmic scale to make the large span of edge roughnesses visible. All substrates show a similar behavior: with increasing exposure dose the edge roughness decreases and stabilizes at a characteristic optimal value. Interestingly the determination of the optimal dose from the analysis of the contrast curves and the investigation of the edge roughness lead to almost exactly the same dose values as can be seen in Table 3.

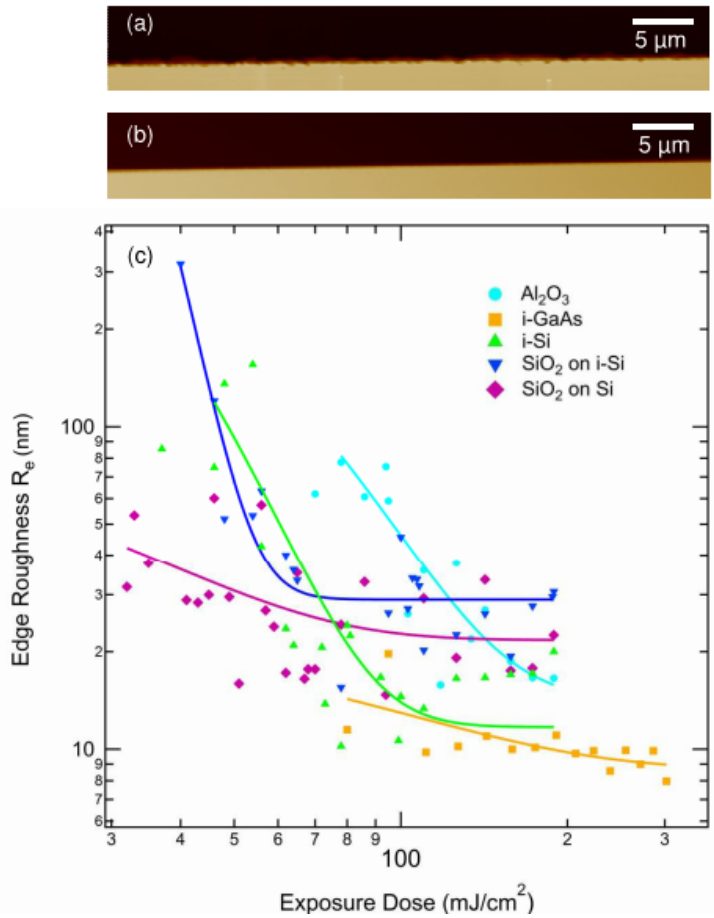

Figure 4. (a) AFM image section in the case of low exposure dose. (b) AFM image section for optimal exposure dose. (c) Measured edge roughness versus exposure dose for all five substrates

Conclusion

We optimized a double layer resist system for lift-off processing. The process is applicable for various substrates such as sapphire, i-GaAs, i-Si, SiO_2 on i-Si and SiO_2 on p-doped Si, which are relevant for ultra-high frequency on-chip experiments. The optimal exposure doses were determined and the contrast curves were generated for five different substrates. We obtain normalized contrast curves that follow an exponential course for all substrates. Depending on the substrate, the optimal exposure dose has a value between 70 and 160 mJ/cm^2. The contrast values are between 1.9 and 3.4, which corresponds to the expected range for positive optical resists. The edge roughness is an important parameter for optimizing the process. The edge roughness values have been determined at the optimum exposure doses and have been found to range from 10 to 36 nm. The edge roughness versus exposure dose follow an exponential course for all substrates before they stabilize at a characteristic optimal value. The edge roughness values are excellent when considering the wavelength of the UV light used in the laser lithography process.

Verweise / References

Chapter 1.

1. Вибрации в технике. В 6 томах под ред. В.Н.Челомея. М.: Машиностроение. Т.1. 1978. С. 352.

2. Вольмир А.С. Устойчивость деформируемых систем. - в 2-х томах. - Изд. 3. Изд. Юрайт, 2011. - 526 с.

3. Камке Э. Справочник по обыкновенным дифференциальным уравнениям. - М., Наука, 1971. - 576 с.

4. Потураев В,Н., Равцов М.В. Основы методики инженерных расчетов машин шарошечного бурения. - В кн.: Надежность горных и транспортных машин. – К., Наукова думка, 1985. – с. 111-116.

5. Пановко Я.Г., Губанова И.И. Устойчивость и колебания упругих систем. - М., Наука, 1969. - 420 с.

6. Тимошенко С.П., Янг Д.Ч.,Уивер У. Колебания в инженерном деле. - М., Наука, 1985. - 444 .

7. Вульфсон И.И., Коловский М.З. Нелинейные задачи динамики машин. - М., Машиностроение, 1969. - 282 с.

8. Кумабе Д. Вибрационное резание. - М., Машиностроение. 1985. - 424 с.

9. Биргер И.А., Шорр Б.Ф., Йосилевич Г.Б. Расчет на прочность деталей машин. - М., Машиностроение, 1979. - 702 с.

Chapter 2.

1. Лацис А.О. Как построить и использовать суперкомпьютер. – М.: Бестселлер. 2003, - 240 с.

1. ФАО. 2020. Состояние мирового рыболовства и аквакультуры – 2020. Меры по повыш ению устойчивости. Рим, ФАО. https://doi.org/10.4060/ca9229ru (дата звернення 10.10.2020 р.)

2. Белоусова, І. А. «Методологічні засади посилення економічної безпеки України в контексті формування продовольчої безпеки.» *Вчені записки Університету «КРОК»* 1 (53) (2019): 145-150.

3. Онопрієнко, Володимир, et al. «Продовольча безпека – як складова сталого розвитку україни.» *Редакційна колегія* (2019): 26.

4. Про державну підтримку сільського господарства України: закон України від 24 червня 2004 року № 1877-IV // Відомості Верховної Ради України, 2004. № 49. Ст. 527.

5. Сидорова, И. Г. «Концепция WELLNESS в медицинском дискурсе (на

материале русскоязычных и англоязычных текстов интернет-сайтов о здоровом образе жизни)» *К 63 Коммуникативные стратегии и лингвокогнитивные механизмы порождения профессионального дискурса: Сборник научных статей. Иркутск: ИГМУ, 2019. 172 с.* (2019): 137.

6. Смычков, О. А. «ОСНОВНЫЕ КОМПОНЕНТЫ ЗДОРОВОГО ОБРАЗА ЖИЗНИ МОЛОДЕЖИ.» *Инновационная наука* 5 (2019). С. 184-185.

7. Потапчик, Е. Г. "Экономические механизмы мотивации граждан к следованию здоровому образу жизни: международный опыт." *Профилактическая медицина* 22.2 (2019): 32-37.

8. Сафонова, О. А., О. В. Рудая, and М. В. Антонова. «Здоровый образ жизни и правильное питание в молодежной среде» Введение. «*Общетеоретические и отраслевые проблемы науки и пути их*».(2019): 46.

9. Україну накрила епідемія вегетаріанства. URL: https://www.unian.ua/society/2297556-ukrajinu-nakrila-epidemiya-vegetarianstva-zmi.html. (дата звернення 10.09.2019 р.)

10. Comas-Basté, Oriol, et al. "Histamine and other biogenic amines in food. From scombroid poisoning to histamine intolerance." Biogenic Amines. IntechOpen, 2019.

11. Безусов А.Т., Манолі Т.А., Нікітчіна Т. І., Баришева Я.О. Щодо питання про утворення біогенних амінів у харчових продуктах // Наук. пр. / Одес. нац. акад. харч. технологій. Одеса, 2018. Т. 82, вип. 2. С. 40 – 46.

12. Серпунина Л.Т. Оценка безопасности рыбных консервов по уровню гистамина // Известия КГТУ, 2013. № 29. С. 115-122.

13. Манолі Т.А., Баришева Я., Нікітчіна Т., Менчинська А. Вплив технологічних факторів на рівень гістаміну рибних продуктів у драглеподібній заливці. Стаття. Продовольча індустрія АПК, 2019. № 1-2. С. 13-17.

14. Venugopal V. Marine products for healthcare : functional and bioactive nutraceutical compounds from the ocean // CRC Press is an imprint of the Taylor & Francis Group, an informa business. 2017. Vol. 5, No. 10. P. 20-27.

15. Haas H., Panula P. The role of histamine and the tuberomamillary nucleus in the nervous system // Nat. Rev. Neurosci. 2003. Vol. 4. P. 121–130.

16. .Akdis C. A., Blaser K. Histamine in the immune regulation of allergic infl ammation // J. Allergy.Clin. Immunol. 2003. Vol. 112. P. 15–22.

17. Gale E. F. // Adv. Enzymol. 1946. Vol. 6. P. 1 31

18. Akdis, Cezmi A., and Kurt Blaser. "Histamine in the immune regulation of allergic inflammation." *Journal of allergy and clinical immunology* 112.1 (2003): 15-22.

19. Hattori Y, Seifert R. «Histamine and Histamine Receptors in Health and Disease», 2017. P. 141-160.

20. Hattori Y, Seifert R. «Histamine and Histamine Receptors in Health and Disease», 2017. P .277-301.

21. Jutel M, Akdis M, Akdis CA (2009) Histamine, histamine receptors and their role in immune pathology. Clin Exp Allergy 39:1786–1800. doi:10.1111/j.1365-2222.2009.03374 x

22. Haas H, Panula P. «The role of histamine and the tuberomamillary nucleus in the nervous system» Nat Rev Neurosci 2003. Vol. 4. P. 121-130.

23. The role of histamine on cognition / Alvarez E. O. // Behavioural brain research. 2009. Vol. 199. №. 2. P. 183-190.

24. СанПин 42-123-4083-86 «Про затвердження Державних санітарних правил і норм для підприємств і суден, що виробляють продукцію з риби та інших водних живих ресурсів»

25. Fusek, Michal, et al. "Modelling biogenic amines in fish meat in Central Erope using censored distributions." *Chemosphere* (2020): 126390.

26. Ruiz-Capillas, Claudia, and Ana M. Herrero. "Impact of biogenic amines on food quality and safety." *Foods* 8.2 (2019): 62.

27. Морозов, А.А. Определение биогенных аминов в водных ресурсах и продукция из них // Известия КГТУ. Калининград, 2010, № 17. – С. 79-83.

28. Подсосонная М.А., Родина Т.Г. Проблема гистамина в рыбной продукции // Известия высших учебных заведений. Пищевая технология, 2004. №1. С. 30-32.

29. Чащина С.Л., Серпунина Л.Т. Исследование уровня гистамина в рыбных консервах в процессе их хранения // Актуальные проблемы освоения биологических ресурсов Мирового океана: материалы междунар. научн.-практ. конф. Владивосток, 2010. С. 54-58.

30. Кизеветтер И.В. К вопросу о накоплении гистамина в тканях тела тихоокеанской скумбрии // Известия ТИНРО. Владивосток, 1972. Т. 83. С. 27-34.

31. Gram, L., and Huss, H. H. (1996). Microbiological spoilage of fish and fish products. Int. J. Food Microbiol.33, 121–137.

32. Glória, M. B. A., Daeschel, M. A.,Craven, C., Hilderbrand, K. S. Jr.(1999). Histamine and other bio-genic amines in Albacore tuna. J.Aquatic Food Prod. Technol. 8,55–69.

33. Özogul F, Özogul Y. Biogenic amine content and biogenic amine quality indices of sardines (Sardina pilchardus) stored in modified atmosphere packaging and vacuum packaging. Food Chemistry. 2006;99 : 574–578.

34. Klausen, Niels Kristian, and Erik Lund. "Formation of biogenic amines in herring and mackerel." Zeitschrift fuer Lebensmittel-Untersuchung und Forschung 182.6 (1986): 459-463.

35. Á. MARCOBAL, P. J. MARTÍN-ÁLVAREZ, M. C. POLO, R. MUÑOZ, and M. V. MORENO-ARRIBAS (2006) Formation of Biogenic Amines throughout the Industrial Manufacture of Red Wine. Journal of Food Protection: February 2006, Vol. 69, No. 2, pp. 397-404.

36. Buteau, C., Duitschaever, C.L. & Ashton, G.C., 1984. A study of the biogenesis of amines in a Villard Noir wine. Am. J. Enol. Vitic. 35, 228-236.

37. Le Jeune, Christine, et al. "Development of a detection system for histidine decarboxylating lactic acid bacteria based on DNA probes, PCR and activity test." Journal of Applied Bacteriology 78.3 (1995): 316-326.

38. Кушнерева Е. В., Марковский М. Г., Гугучкина Т. И., Агеева Н. М. Определение содержания биогенных аминов в виноградных винах // Известия ВУЗов. Пищевая технология. 2012. №1. С.106-108.

39. Lonvaud-Funel, Aline, and Annick Joyeux. "Histamine production by wine lactic acid bacteria: isolation of a histamine-producingstrain of Leuconostoc oenos." Journal of Applied Bacteriology 77.4 (1994): 401-407.

40. Серпунина, Л. Т., and Е. В. Бречко. "Уровень гистамина в рыбных консервах в зависимости от технологических факторов." Известия КГТУ 23 (2011): 191-198.

41. Straub, Bernhard W., et al. "The formation of biogenic amines by fermentation organisms." Zeitschrift für Lebensmittel-Untersuchung und Forschung 201.1 (1995): 79-82.

42. Fernández M, Linares D M, Rodríguez A, Alvarez M A. Factors affecting tyramine production in Enterococcus durans IPLA 655. Applied Microbiology and Biotechnology. 2007;73:1400–1406.

43. Burdychová R, Komprda T. Biogenic amine-forming microbial communities in cheese. FEMS Microbiology Letters. 2007;276:149–155.

44. Novella-Rodríguez S, Veciana-Nogués M T, Izquierdo-Pulido M M, Vidal-Carou M C. Distribution of biogenic amines and polyamines in cheese. Journal of Food Science. 2003;68:750–755.

45. Burdychová R, Komprda T. Biogenic amine-forming microbial communities in cheese. FEMS Microbiology Letters. 2007;276:149–155.

46. Stute, R., et al. "Biogenic amines in fish and soy sauces." European Food Research and Technology 215.2 (2002): 101-107.

47. Л.Г. Нетюхайло. Метаболізм амінокислот, специфічні шляхи

перетворень амінокислот, спадкові ензимопатії. Вісник проблем біології і медицини – 2012 – Вип.2, том 1 (92) С.11-13.

48. Straub B. W., P Tichaczek and W. P. Hammes. 1992 Formatiom of tyramine by lactobacilius curvatus tTH 972 in Bilrage des ' Symposiums Aktucilier stand and Trends in det Lebensmittel technologic am 09. and 10 Oktober, Univeristat Hohenheim, Stuttgart.

49. Wang, D., Yamaki, S., Kawai, Y., & Yamazaki, K. (2020). Histamine Production Behaviors of a Psychrotolerant Histamine-Producer, Morganella psychrotolerans, in Various Environmental Conditions. Current Microbiology, *77*(3), 460-467.

50. Lonvaud-Funel, A. (2001) Biogenic amines in wines: role of lactic acid bacteria. FEMS Microbiol Lett 199, 9–13.

51. Пенчук, Юрій Миколайович, and Юрий Николаевич Пенчук. "Сучасний стан та перспективи біотехнологічних методів виробництва амінокислот." (2012).

52. Lehane, L., and Olley, J. (2000). Histamine fish poisoning revisited. Int. J.Food Microbiol. 58, 1–37.

53. Kim, S. H., Price, R. J., Morrissey, M.T., Field, K. G., Wei, C. I., and An,H. (2002b). Histamine production by Morganella morganii in mackerel, albacore, mahi-mahi, and salmon at various storage temperatures. J. Food Sci. 67, 1522–1528.

54. Gale E. F. // Biochem. J. 1940. Vol. 34. P. 392-413

55. Kranner, P., F. Bauer, and E. Hellwig. "Investigations on the formation of histamine in raw sausages." *International Congress of Meat Science and Technology*. Vol. 37. 1993.

56. Chander B., V.K. Batish. S Babu, and K. L. Bhatia. 1988. Studies on optimal conditions for amine production by E. coii. Milchwissenshaf, 43: 90-91.

57. Bremer PJ, Fletcher GC, Osborne C. 2003. Scombrotoxin in seafood. Christchurch , New Zealand : New Zealand Institute for Crop & Food Research Limited.

58. Bover-Cid S, Hugas M, Izquierdo-Pulido M, Vidal-Carou MC. 2000a. Reduction of biogenic amine formation using a negative amino acid-decarboxylase starter culture for fermentation of Fuet sausages. J Food Prot 63:237–43.

59. Osborne CM, Bremer PJ. 2000. Application of the bigelow (z-value) model and histamine detection to determine the time and temperature required to eliminate Morganella morganii from seafood. J Food Prot 63(2):277–80(274).

60. Kang IJ, Park YH. 1984. Effect of food additives on the histamine formation during processing and storage of mackerel. Bull Korean Fisheries Soc 17:383.

61. Özogul, F., et al. "Biogenic amines formation in Atlantic herring (Clupea harengus) stored under modified atmosphere packaging using a rapid HPLC method." *International Journal of Food Science & Technology* 37.5 (2002): 515-522.

62. Колганов Е.В., Дозорова М.С., Мурашов И.Д. Применение лазерного излучения для уменьшения микробиологической обсемененности мяса и мясных продуктов. М.2010.

63. Быкова В.М., Белова З.И. Справочник по холодильной обработке рыбы. М.: Агропромиздат, 1986. 208с.

64. Михайлова Н.Ф., Родин Е.М. Совершенствование способов холодильной обработки и хранения рыбы. М.: Агропромиздат, 1987. 208с.

65. Родин Е.М. Холодильная технология рыбных продуктов. М.: Агропромиздат, 1989. 303с.

66. ГОСТ 7631−85. Рыба, морские млекопитающие, морские беспозвоночные и продукты их переработки. Правила приемки, органолептические методы оценки качества, методы отбора проб для лабораторных испытаний. [Введен 1986–01–01]. М.: Издательство стандартов, 1991. 26 с.

67. ГОСТ 7636–85. Рыба, морские млекопитающие, морские беспозвоночные и продукты их переработки. Методы анализа. [Введен 1986–01–01]. М.: Изд–во стандартов, 1985. 75 с.

68. ГОСТ 28972-91 Группа Н59 Межгосударственный стандарт. Консервы и продукты из рыбы и нерыбных объектов промысла. Метод определения активной кислотности (pH) Canned fish and other seaproducts. Method for determination of actual acidity (pH) МКС 67.120.30 ОКСТУ 9209 Дата введения 1992-07-01.

69. ДСТУ 8446:2015 Продукти харчові. Методи визначення кількості мезофільних аеробних та факультативно-анаеробних мікроорганізмів. [Чинний від 2017-07-01]. Київ: Держстандарт України, 2015. 16 с.

70. ГОСТ 10444.15-94 Продукты пищевые. Методы определения количества мезофильных аэробных и факультативно-анаэробных микроорганизмов. – Дата введ. 1996—01—01– ПРИНЯТ Межгосударственным советом по стандартизации, метрологии и сертификации (протокол № 6 от 21 октября 1994 г.) Издательство стандартов, 1994. 5 с.

71. ГОСТ 10444.12-88 Межгосударственный стандарт. Продукты пищевые. Метод определения дрожжей и плесневых грибов. Food products. Method for determination of yeast and mould. МКС 07.100.30. ОКСТУ 9109. Дата введения 1990-01-01. 6 с.

72. ДСТУ 8069:2015 Продукти перероблення фруктів та овочів. Титриметричний метод визначення пектинових речовин. Дата введения 2017-01-01. 13 с.

73. Методы контроля. Биологические и микробиологические факторы. Санитарно-эпидемиологическая оценка обоснования сроков годности и условий хранения пищевых продуктов. URL: http://www.businesspravo.ru/Docum/DocumShow_DocumID_91319. (дата звернення: 25.09.2019).

74. Баришева Я.О., Манолі Т.А., Безусов А.Т. Дослідження впливу пектинових речовин на вміст біогенних амінів у рибних кулінарних виробах. Зб. тез. VIII Міжнародної науково-практичної конференції вчених, аспірантів і студентів «Наукові здобутки у вирішенні актуальних проблем виробництва та переробки сировини, стандартизації і безпеки продовольства», 17-18 квітня 2019 р. НУБіП Київ, 2019. С. 159.

75. Barysheva Y., Glushkov O., Manoli T., Nikitchina T., Bezusov A. A technology developed to produce hot fish marinades for a jellylike filling of prolonged storage / - Eastern-European Journal of Enterprise Technologies. 2017. 5/11 (89) 2017. С. 40–45.

76. Инструкция по санитарно-микробиологическому контролю производства пищевой продукции из рыбы и морских беспозвоночных Инструкция по санитарно-микробиологическому контролю производства пищевой продукции из рыбы и морских беспозвоночных, МЗ СССР N 5319-91 от 22.02.91.

77. Безусов А.Т., Нікітчіна Т.І. Саркісян Г.О. Розробка способу одержання продуктів із біохімічно модифікованих пектинових речовин поліфенолами рослинної сировини. Наукові праці [ОНАХТ]. 2016. Том 80, Вип. 2. С. 13–16.

78. Бек М., Надьпал И. Исследования комплексообразования новейшими методами. М.: Мир. 1989. 413с.

79. Временные гигиенические нормативы и методы определения содержания гистамина в рыбопродуктах: СанПиН 42-123-4083-86. Режим доступу: https://dokipedia.ru/document/5182267 – Назва з екрана.

80. Биологическая активность фукоиданов из бурых водорослей и перспективы их применения в медицине/ Кузнецова Т.А., Шевченко Н.М., Звягинцева Т.Н., Беседнова Н.Н.// Антибиотики и химиотерапия.- 2004.- 49, № 5.- С. 24-30.

Chapter 3.

1. Artiukh V., Mazur V., Pokrovskaya E. Influence of Strip Bite Time in Work Rolls Gap on Dynamic Loads in Strip Rolling Stands. MATEC Web of Conferences. 2016, Vol. 86, 01030 p.

2. Artiukh V., Mazur V., Prakash R.V. Increasing Hot Rolling Mass of Steel Sheet Products. Materials Science Forum. 2016, Vol. 871, pp. 3–8.

3. Kukhar V., Balalayeva E., Prysiazhnyi A., Vasylevskyi O., Marchenko I. Analysis of relation between edging ratio and deformation work done in pre-forming of workpiece by bulk buckling. MATEC Web of Conferences. 2018, Vol. 178, 02003 p.

4. Mazur V.L., Timoshenko V.I., Prikhod'ko I.Y. Regulating the Coil Stress by Adjusting the Rigidity of the Winding Drum. Steel in Translation. 2018, Vol. 48(8), P. 528–535.

5. Kim J., Lee J., Hwang S.M. An analytical model for the prediction of strip temperatures in hot strip rolling. International journal of heat mass transfer. 2009, Vol. 52, pp. 1864–1874.

6. Kurpe O.H., Kukhar V.V., Klimov E.S., Chernenko S.M. Improvement of Process Parameters Calculation for Coil Rolling at the Steckel Mill. Materials Science Forum. 2020, Vol. 989, pp. 609–614.

7. Kurpe O.H., Kukhar V.V. Development and Optimization of Flat Products Manufacturing at Rolling Mill 3200. Materials Science Forum. 2018, Vol. 946, pp. 794–799.

8. Anishchenko O.S., Kukhar V.V., Grushko A.V., Vishtak I.V., Prysiazhnyi A.H., Balalayeva E.Yu. Analysis of the Sheet Shell's Curvature with Lame's Superellipse Method during Superplastic Forming. Materials Science Forum. 2019, Vol. 945, pp. 531–537.

9. Anishchenko A., Kukhar V., Artiukh V., Arkhipova O. Application of G. Lame's and J. Gielis' formulas for description of shells superplastic forming. MATEC Web of Conferences. 2018, Vol. 239, 06007 p.

10. Artiukh V., Kukhar V., Balalayeva E. Refinement issue of displaced volume at upsetting of cylindrical workpiece by radial dies. MATEC Web of Conferences. 2018, Vol. 224, 01036 p.

11. Xu. Y, Yu. Y, Liu. X, Wang G. Modeling of microstructure evolution and mechanical properties during hot-strip rolling of Nb steels. Journal of University of Science and Technology. Beijing. 2008, Vol. 15, pp. 396–401.

12. Schausberger F., Steinboeck A., Kugi A. Mathematical modeling of the contour evolution of heavy plates in hot rolling. Applied Mathematical Modelling.

2015, Vol. 39, pp. 4534–4547.

13. Quan-Ke Pan, Qing-da Chen, Tao Meng, Bing Wang, Liang Gao. A mathematical model and two-stage heuristic for hot rolling scheduling in compact strip production. Applied Mathematical Modelling. 2017, Vol. 48, pp. 516–533.

14. Rudkins, N., Evans, P. Mathematical modelling of mill set-up in hot strip rolling of high strength steels. Journal of Materials Processing Technology. 1998, Vol. 80-81, pp. 320–324.

15. Ettl A., Prinz K, Mueller M., Steinboeck A., Kugi A. Mathematical Model and Stability Analysis of the Lateral Plate Motion in a Reversing Rolling Mill Stand. IFAC-PapersOnLine. 2018, Vol. 51(2), pp. 73–78.

16. Phaniraj M.P., Behera B.B., Lahiri A.K. Thermo-mechanical modeling of two phase rolling and microstructure evolution in the hot strip mill Part I. Prediction of rolling loads and finish rolling temperature. Journal of Materials Processing Technology. 2005, Vol. 170, pp. 323–335.

17. Orlov G.A., Orlov A.G. Simulation of Roller-Type Cold Rolling of Tubes. Metallurgist. 2019, Vol. 62(9-10), pp. 857–863.

18. Jamal F., Rath S., Acherjee B. Process modelling of flat rolling of steel. Advances in Materials and Processing Technologies. 2018, Vol. 5(1), pp. 1–10.

19. Markov O.E., Gerasimenko O.V., Shapoval A.A., Abdulov O.R., Zhytnikov R.U. Computerized simulation of shortened ingots with a controlled crystallization for manufacturing of high-quality forgings. International Journal of Advanced Manufacturing Technology. 2019, Vol. 103 (5-8), pp. 3057–3065.

20. Weisz-Patrault D. Coupled heat conduction and multiphase change problem accounting for thermal contact resistance. International Journal of Heat and Mass Transfer. 2017, pp. 595–606.

21. Weisz-Patrault D., Ehrlacher A., Legrand N. Temperature and heat flux fast estimation during rolling process. International Journal of Thermal Sciences. 2014, pp. 1–20.

22. Weisz-Patrault D. Inverse three-dimensional method for fast evaluation of temperature and heat flux fields during rolling process. Symposium on Modelling of Rolling Processes, France. 2012, pp. 20–22.

23. Efremenko V.G., Zurnadzhi V.I., Chabak Y.G., Tsvetkova O.V., Dzherenova A.V. Application of the Q-n-P-Treatment for Increasing the Wear Resistance of Low-Alloy Steel with 0.75% C. Material Science. 2017, Vol. 53, pp. 67–75.

24. Anishchenko A., Kukhar V., Artiukh V., Arkhipova O. Superplastic forming of shells from sheet blanks with thermally unstable coatings. MATEC Web of Conferences. 2018, Vol. 239, 06006 p.

25. Tarelnyk V., Martsynkovskyy V., Gaponova O., Konoplianchenko I., Dovzyk M., Tarelnyk N., Gorovoy S. New sulphiding method for steel and cast iron parts. IOP Conference Series: Materials Science and Engineering. 2017, Vol. 233, 012049 p.

26. Shao Z., Wang Z., Li Z., Wang S., Wang J. Effect of thermomechanical processing on the microstructure and mechanical properties of low carbon steel, Proc. of the 5th International conference on advanced design and manufacturing engineering (ICADME 2015). Advances in Engineering Research, Shenzhen, China. 2015, pp. 1984–1989.

27. Kukhar V., Kurpe O., Klimov E., Balalayeva E., Dragobetskii V. Improvement of the Method for Calculating the Metal Temperature Loss on a Coilbox Unit at The Rolling on Hot Strip Mills. International Journal of Engineering & Technology, 7(4.3) (2018) 35-39.

28. J. G. Lenard, Mathematical and Physical Modelling of the Flat Rolling Process. Primer on Flat Rolling. Elsevier Ltd. 2007, Vol. 3, pp. 36–98.

29. Mantyla P., Korhonen R., Jonsson N-G. Improved Thickness and Shape Accuracy with Advanced Pass Scheduling in Plate Rolling. Journal of Materials Processing Technology. 1992, Vol. 34, pp. 255–263.

30. Yue S. The Mathematical Modelling of Hot Rolling of Steel. Metal Forming Science and Practice. Published by Elsevier Science Ltd. 2002, Vol. 11, pp. 213–226.

31. Radionova L.V., Chernyshev A.D., Lisovskiy R.A. Interactive Educational System – Virtual Simulator "Sheet Rolling". Procedia Engineering. 2017, Vol. 206, pp. 512–518.

32. Galantucci L.M., Tricarico L. Thermo-mechanical simulation of a rolling process with an FEM approach. Journal of Materials Processing Technology, 1999, Vol. 92–93, pp. 494–501.

33. Hanoglu U., Šarler B. Multi-pass hot-rolling simulation using a meshless method. Computers and Structures. 2018, Vol. 194, pp. 1–14.

34. Kukhar V., Prysiazhnyi A., Balalayeva E., Anishchenko O. Designing of induction heaters for the edges of pre-rolled wide ultrafine sheets and strips correlated with the chilling end-effect. Modern Electrical and Energy System, MEES'2017, IEEE, Kremenchuk, 2017, pp. 404–407.

35. Matruprasad Rout, Surjya K. Pal, Shiv B. Singh. Finite element simulation of a cross rolling process. Journal of Manufacturing Processes. 2016, Vol. 24, pp. 283–292.

36. Lee D.M. Applications to improve rolling force prediction ability in a plate mill. Automation in Mining, Mineral and Metal Processing. IFAC Proceedings. 2004,

Vol. 37(15), pp. 65–70.

37. Yuen W.Y.D., Dixon A., Nguyen D.N. The modelling of the mechanics of deformation in flat rolling. Journal of Materials Processing Technology. 1996, Vol. 60, pp. 87–94.

38. Jin-ling Zhang, Zhen-shan Cui. Prediction of Velocity and Deformation Fields During Multipass Plate Hot Rolling by Novel Mixed Analytical-Numerical Method. Journal of Iron and Steel Research. International. 2011, Vol. 18(7), pp. 20–27.

39. Min-ting Wang, Xin-liang Zang, Xue-tong Li, Feng-shan Du. Finite Element Simulation of Hot Strip Continuous Rolling Process Coupling Microstructural Evolution. Journal of Iron and Steel Research. International. 2007, Vol. 14(3), pp. 30–36.

40. Xian-lei Hu, Zhong Zhao, Jun Wang, Zhao-dong Wang, Xiang-hua Liu, Guo-dong Wang. Optimization of Holding Temperature and Holding Thickness for Controlled Rolling on Plate Mill. Journal of Iron and Steel Research. International. 2006, Vol. 13(3), pp. 21–25.

41. Xiang-dong Qi, Tao Wang, Hong Xiao. Optimization of Pass Schedule in Hot Strip Rolling. Journal of Iron and Steel Research. International. 2012, Vol. 19(8), pp. 25–28.

42. Fedorinov V.A., Satonin A.V., Gribkov Je.P. Matematicheskoe modelirovanie naprjazhenij, deformacij i osnovnyh pokazatelej kachestva pri prokatke otnositel'no shirokih listov i polos. monogr., Kramatorsk, DGMA. 2010, 244 p. [In Russian].

43. Konovalov Ju.V., Ostapenko A.L., Ponomarev V.I. Raschet parametrov listovoj prokatki. Spravochnik, Moskva, Metallurgija. 1986, 430 p. [In Russian].

44. Kukhar V., Artiukh V., Prysiazhnyi A., Pustovgar A. Experimental Research and Method for Calculation of 'Upsetting-with-Buckling' Load at the Impression-Free (Dieless) Preforming of Workpiece. E3S Web of Conference. 2018, Vol. 33, 02031 p.

45. Prysiazhnyi A.H., Kukhar V.V., Balalayeva E.Yu. Method for Determining the Optimum Counter-Flexing Force of Working Rolls during Sheet Rolling. Solid State Phenomena. 2018, Vol. 284, pp. 416–424.

46. Minaev A.A., Nosanev A.G., Smirnov E.N., Bublik P.F , Shishkevich V.V. Unit for accelerated cooling of reinforcement bars in the line of a 330 mill after deformation. Metallurgist. 1990, 32 p.

Chapter 4.

1. M. Rini, R. Tobey, N. Dean, J. Itatani, Y. Tomioka, Y. Tokura, R. W. Schoenlein, and A. Cavalleri, Nature 449, 72 (2007)

2. N. Hunter, A. S. Mayorov, C. D. Wood, C. Russell, L. Li, E. H. Linfield, A. G. Davies, and J. E. Cunningham, Nanolett. 15, 1591 (2015)

3. D. N. Basov, R. D. Averitt, D. Hsieh, Nat. Mat. 16, 1077 (2017)

4. M. Mitrano, A. Cantaluppi, D. Nicoletti, S. Kaiser, A. Perucchi, S. Lupi, P. Di Pietro, D. Pontiroli, M. Riccò, S. R. Clark, D. Jaksch, and A. Cavalleri, Nature 530, 461 (2016)

5. E. J. Sie, J. W. McIver, Y.-H. Lee, L. Fu, J. Kong and N. Gedik, Nature Mat. 14, 290 (2015)

6. A. Brenneis, L. Gaudreau, M. Seifert, H. Karl, M. S. Brandt, H. Huebl, J. A. Garrido, F. H. L. Koppens, and A. W. Holleitner, Nature Nano. 10, 135 (2015)

7. J. McIver, B. Schulte, F.-U. Stein, T. Matsuyama, G. Jotzu, G. Meier and A. Cavalleri, submitted (2018)

8. D. H. Auston, IEEE J. Quant. Electr. QE-19, 639 (1983)

9. D. Grischkowsky, I. N. Duling, III, J. C. Chen, and C.-C. Chi, Phys. Rev. Lett. 59, 1663 (1987)

10. L. Prechtel, L. Song, D. Schuh, P. Ajayan, W. Wegscheider, and A. W. Holleitner, Nature Comm. 3, 646 (2012)

11. V.S. Osadchuk, O.V. Osadchuk, O.M. Zhaglovskaya. Radio-measuring microelectronic converters of frequency output optical radiation. - Vinnytsia: National Technical University, 2016. - 168 p. ISBN 978-966-641-652-3

12. Functional Nanostructures and Sensors for CBRN Defence and Environmental Safety and Security. A.Sidorenko, H.Hahn. 12, p. 161- 184, ISBN 978-94-024-1911-5, (2018), https://doi.org/10.1007/978-94-024-1909-2

13.Datasheets: http://microchem.com/pdf/PMGI-Resists-data-sheetV-rhcedit-102206.pdf

14. Optimization of Bi-layer Lift-Off Resist Process. J. Golden, H. Miller, D. Nawrocki, J. Ross, CS MANTECH Conference, Tampa, Florida, USA, May 18th-21st (2009)

15. A. Aassime, F. Bayle, M. P. Plante, F. Hamouda, Micro. Engineering 168, 62 (2017)

16.Datasheets:https://www.microresist.de/sites/default/files/download/PI_maP1275_hv_2015_1.pdf; https://www.microresist.de/de/product/positiv-photoresiste-2

17. Photolithography - Basics of Microstructuring, MicroChemicals, C. Koch, T. J. Rinke, ISBN 978-3-9818782-0-2 (2017)

18. https://www.lpkf.de/produkte/rapid-pcb-prototyping/laserstrukturierung/laser- mikromaterialbearbeitung-u4.htm

19. https://de.elgalabwater.com/products-de/purelab-de/purelab-classic-de

20. https://www.sps-europe.com/order/spin150i-ptfe-int-single-substrate-spin-processor/15878/

21. https://www.leicamicrosystems.com/de/produkte/lichtmikroskope/clinical/details/product/leica-dm3000/

22. https://www.bruker.com/de/products/surface-and-dimensional-analysis/atomic-force-microscopes/dimension-icon/overview.html

23. https://www.himt.de/index.php/upg-101.html

24.https://www.microchemicals.com/fileadmin/user_upload/TechnicFrance/SPEC/spec_Isopropanol_VLSI.pdf

25.http://www.wintervakuumtechnik.com/produkte/vakuumbeschichtungssysteme/

26. Datasheet: remover mr Rem 700 https://www.microresist.de/en/product/positive/photoresists-2

Chapter 5.

1. Костырко Я.-В.И., Романюк Ю.Ф., Ожоган В.А. К вопросу определения периодичности предупредительных ремонтов двигателей электробуров // Пром. энергетика, 1986. - №7. – С. 22-24.

2. Костирко Я.-В.І., Ожоган В.А., Федорів М.Й., Галущак І.Д. Електробур – перспектива і дослідження його надійності // Тези НТК ПВС ун-ту, ІІ ч. – Івано-Франківськ, 1995. – С.89.- (Секція ФАЕ).

3. Ожоган В.А., Федорів М.Й., Галущак І.Д. Комутаційні перенапруги в системах електропостачання електробурів // Тези НТК ПВС ун-ту, ІІ ч. – Івано-Франківськ, 1997. – С. 174. – (Секція ФАЕ).

4. Яремійчук Р.С., Байдюк Б.В. Напрямки створення української технології буріння свердловин, конкурентноспроможної на світовому рівні. – Нафтова і газова промисловість. – 1997. - №4. – С. 17-18.

Chapter 6.

1. Стратегія інноваційного розвитку України на 2010-2020 роки в умовах глобалізаційних викликів: Матеріали парламентських слухань у Верховній Раді України 17 червня 2009 року / За заг. ред. проф. В.І. Полохала. – К.: Парламентське видавництво, 2009. – 630 с.

2. Редкін О.В. Стратегічне та проектне управління інноваційним розвитком національного господарства, його високотехнологічних науково-виробничих