Optica Applicata, Vol. XLVI, No. 2, 2016
DOI: 10.5277/oa160209

Improvement of the electron beam lithography contact pads fabrication process

KORNELIA INDYKIEWICZ*, REGINA PASZKIEWICZ, BOGDAN PASZKIEWICZ

Wrocław University of Science and Technology, Faculty of Microsystem Electronics and Photonics, Janiszewskiego 11/17, 50-372 Wrocław, Poland

*Corresponding author: kornelia.indykiewicz@pwr.edu.pl

In the paper, the verification of using the electron beam lithography technique as a main lithography tool for device fabrication is presented. The results of conducted experiments allow us to minimize the exposition time of big areas and retain acceptable metallic structures resolution and designed distances for structures in the neighborhood of a few micrometers. Conducted statistical analysis allows us to define the significance of the selected factors influence on the objectives of this study.

Keywords: electron beam lithography (EBL), exposition of big areas, exposition time optimization.

1. Introduction

Electron beam lithography (EBL) is a high resolution technique that is not commonly used in a micro- and nano-electronics industry as a main technique. Due to low technological yield, it is used mostly in the high precision steps [1, 2] or for mask fabrication [3]. Nevertheless, EBL could be used as a main lithography process, also for exposition of big areas, during devices fabrication process. Such a situation can take place where the time of exposition process is not crucial, for example while developing a new concept of devices layout. It gives an opportunity for flexible processes design.

To make EBL technique practically useable as a main lithography technique, it must fulfill both the requirements of low exposition time and simultaneously high resolution Therefore, the exposition of big areas by electron beam lithography must be studied and optimized.

2. Experiment

For the conducted experiments, the AlGaN/GaN HEMT structures with e-beam sensitive resists – PMMA/MA and PMMA – were used. Electron beam lithography was done by PIONEER system. Expositions were conducted for 33 800 μm^2 areas (sum of all structures in every exposition module) in a meander mode with constant area dose –

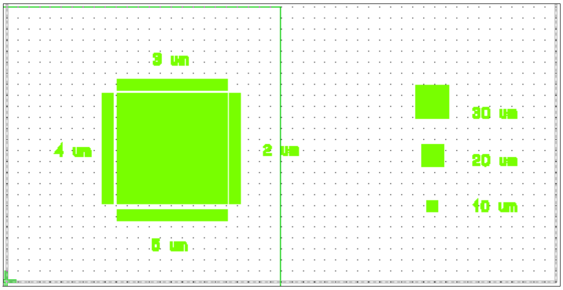

Fig. 1. Part of the mask design.

100 μm/cm^2. The mask design includes the test structures for resolution and quality verification, Fig. 1.

The most important part of the mask design contains long rectangles, situated close to the big area exposition - a square, with distances between them in the range of 2–5 μm. Leaving these distances between the structures after the lift-off process will determine the quality of exposition process. Fabrication of a few micrometers distances between big metallic areas or pads with good resolution in a short time can be applied for the transistor technology, in a source-drain part of device fabrication, leaving space for the gate electrode.

After the TiAu evaporation process, the lift-off process assisted with an ultrasound bath took place. The measurements were done by a scanning electron microscope Hitachi SU 6600. Final metallic structures are presented in Fig. 2.

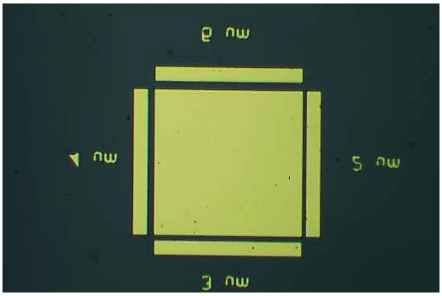

Fig. 2. Metallic test structures – optical microscope.

Selected test parameters were: extra high tension (EHT) value and aperture size, which determines the probe current. These last parameters decide strongly on an exposition time, which is one of the interest of the study. EHT value is responsible for the e-beam penetration depth on the resist stack and the substrate.

The objective of this study was to evaluate the influence of these two parameters on test structures resolution and characterize the best configuration of their values to

T a b l e 1. Parameters and results of conducted experiments.

Aperture [μm]	60	60	60	**60**	**30**	30	30	30
Exposition time [s]	19	16	20	**25**	**95**	76	61	69
Beam current [nA]	1.978	2.241	1.841	**1.431**	**0.339**	0.431	0.525	0.473
EHT [kV]	25	20	15	**10**	**10**	15	20	25
Mean distance 2 μm [μm]	2.65	2.18	1.97	**1.97**	**2.01**	2.05	2.17	2.47
Error [μm]	0.05	0.04	0.01	**0.05**	**0.02**	0.08	0.11	0.05
Mean distance 3 μm [μm]	3.79	3.71	3.43	**3.38**	**3.09**	3.14	3.42	3.45
Error [μm]	0.04	0.08	0.02	**0.02**	**0.03**	0.01	0.17	0.10
Mean distance 4 μm [μm]	–	4.30	3.95	**4.03**	**3.99**	4.04	4.27	4.49
Error [μm]	–	0.10	0.02	**0.02**	**0.02**	0.04	0.14	0.09
Mean distance 5 μm [μm]	–	5.72	5.44	**5.39**	**5.12**	5.25	5.36	5.51
Error [μm]	–	0.07	0.05	**0.02**	**0.03**	0.04	0.10	0.09
Mean area 10×10 μm [$μm^2$]	96.99	96.95	97.57	**99.00**	**102.48**	103.06	102.20	101.62
Mean area 20×20 μm [$μm^2$]	408.63	405.17	407.55	**409.89**	**414.56**	419.2	418.06	415.75

obtain the shortest time of exposition. All the values of technological factors and the results are collected in Table 1.

3. Results

The statistics was developed using the two-way analysis of variance (ANOVA). The experiments were conducted as a 4×2 factorial treatment for the 2 and 3 μm distances and 3×2 for the 4 and 5 μm distances. The experimental factors were: aperture size (two levels: 30 and 60 μm) and EHT value (four levels: 10, 15, 20, 25 kV). The dependent variable was the distance between the test structures, described in the experimental part and shown in Fig. 1. We considered four different distances: 2, 3, 4, and 5 μm. For post-hoc verification, HSD Tukey's test was done. The effects of experiments are illustrated in Figs. 3.

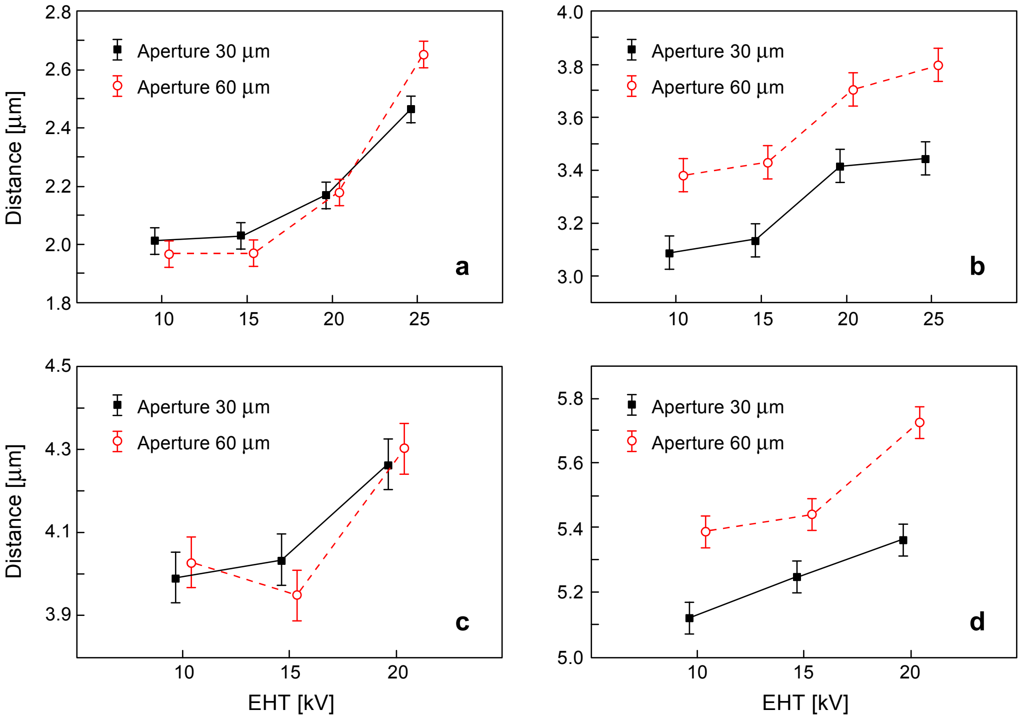

Fig. 3. Average distances between test structures in a function of EHT for 0.95 confidence interval. Design distances: 2 µm (**a**), 3 µm (**b**), 4 µm (**c**), and 5 µm (**d**).

Based on conducted analysis, we can reject the null hypothesis, which states that there is no difference among the mean distances between the test structures for two technological factors used, for all four studied cases. The value of EHT had a significant effect on distance for all conducted cases for $p < 0.001$. Also the main effect of aperture size for distance 3 and 5 µm is statistically significant for $p < 0.001$: $F(1,40)_{3\,\mu m} = 192.83$ and $F(1,30)_{5\,\mu m} = 195.5$. Unfortunately, there is no significant difference for distances 2 and 4 µm.

The interaction for the entire two-way ANOVA was not significant for all distance cases (see Fig. 3). For 2 µm the interaction was strong, $F(3,40) = 12.78$, $p < 0.001$. The interaction for 3 µm was very small, and far from being significant, $F(3,40) = 0.41$, $p < 0.75$. There is a fairly small amount of interaction for 4 µm, $F(2,30) = 2.8$, $p < 0.25$. The effect for 5 µm was qualified by a significant interaction, $F(2,30) = 6.4$, $p < 0.005$.

4. Discussion

Based on conducted data analysis, both experimental factors influence the final result of structures fabrication, what is consistent with the theory. The distances between the test structures increase with a higher value of EHT for both aperture sizes, Table 1.

High beam voltage prevents the increase in an effective beam due to forward scattering in accordance with the empirical formula [4]:

$$d_f = 0.9(R_t/V_b)^{1.5}$$

where R_t is the resist thickness in nanometers and V_b is the beam voltage in kilovolts. Unfortunately, for technological reasons, the used resist thickness for the top layer of an employed stack was approximately 280 nm, what provokes the electron beam proximity effect occurrence for higher EHT values in this region. Because the fabrication of a rectangle which separates the contact pads was done with positive resists, measured distances increase with EHT values. Nevertheless, the closest distances were obtained for 10 kV due to probably not optimized resist developing time.

For all considered distance cases, bigger aperture size determines greater distances between the structures, marked by dashed lines in Figs. 3**a**–3**d**. The tendency of this effect is not homogeneous, which is caused by differences, in some ranges, between the beam current values for every configuration of used technological parameters, Table 1. Also this could be the reason why the main effect of aperture size for 2 and 4 µm distance is not significant.

Exposition time results of conducted experiments and values of used technological parameters are collected in Table 1. Tests with the best effects of average distances between metallic test structures for every aperture size are highlighted. For both cases the best resolution was obtained for 10 kV of EHT and the lowest beam current value. Unfortunately, high resolution is not concurrent with the shortest time of exposition. It is connected with the EHT value influence on the beam current value, which is not constant for conducted tests with selected aperture size: for aperture size 30 µm it is in the range of 0.339–0.525 nA and for 60 µm – in the range of 1.431–2.241 nA.

Results of the areas size for the metallic squares designed as 10×10 µm and 20×20 µm are illustrated in Fig. 4. The best group of technological parameters for these

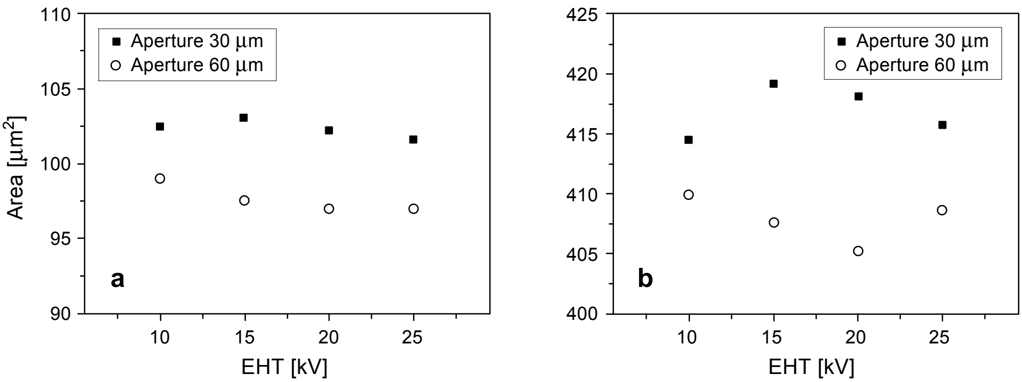

Fig. 4. Area measurements for 10×10 µm (**a**) and 20×20 µm (**b**) metallic pads in a function of applied EHT for 30 µm (■) and 60 µm (○) EBL aperture.

test structures are not the same as for distances. This effect occurs because of different character of fabrication of metallic squares and of distances between the test structures.

5. Conclusions

Conducted experiments allow us to select technological parameters for short exposition time and high resolution at contact pads fabrication with a few micrometers distance between them. Based on two-way ANOVA analysis, we can conclude that EHT value and aperture size strongly influence the resolution of the structures and time of their fabrication. In most cases we can confirm the interactions between these two parameters. The best results of the experiments were obtained with 30 μm aperture and 10 kV EHT in time of exposition 95 s for area size 33 800 μm^2. Over three times shorter time of exposition appeared to be sufficient for a bigger aperture size – 60 μm with only slightly losing the resolution. Obtained results allow us to use the EBL technique for complex device fabrication in laboratory regime at accepted processing time and structures quality.

Acknowledgments – This work was co-financed by the European Union within the European Regional Development Fund, through grant Innovative Economy (POIG.01.01.02-00-008/08-05), by the National Centre for Research and Development through Applied Research Program grant No. 178782, the National Centre for Research and Development through program LIDER grant No. LIDER/027/533/L-533/L-5/13/NCBR/2014, the National Centre for Science under grant No. DEC-2012/07/D/ST7/02583 and by Wrocław University of Science and Technology statutory grants and Slovak-Polish International Cooperation Program No. SK-PL-0005-12.

The project *Interuniversity Didactic-Technological Center 'TECHNOPOLIS' in Wrocław* co-funded by the European Union from the funds of the European Regional Development Fund under the Infrastructure and Environment Programme, No. UDA-POIS.13.01-021/09-00 is greatly acknowledged for SEM/EDX pictures/maps.

References

[1] WANG L.K., TAUR Y., MOY D., DENNARD R.H., CHIONG K., HOHN F., COANE P.J., EDENFELD A., CARBAUGH S., KENNEY D., SCHNUR S., *0.5 micron gate CMOS technology using e-beam/optical mix lithography*, Symposium on VLSI Technology, Digest of Technical Papers, 1986, p. 13–14.

[2] RAHMAN S.F.A., YUSOF N.A., HAMIDON M.N., ZAWAWI R.M., HASHIM U., *Top-down fabrication of silicon nanowire sensor using electron beam and optical mixed lithography*, 2014 IEEE International Conference on Semiconductor Electronics (ICSE), pp. 64–67.

[3] SASAKI S., ITOH K., FUJII A., TOYAMA N., MOHRI H., HAYASHI N., *Photomask process development for next generation lithography*, Proceeding of SPIE **5853**, 2005, pp. 277–288.

[4] RAI-CHOUDHURY P. [Ed.], *Handbook of Microlithography, Micromachining, and Microfabrication. Volume 1: Microlithography*, SPIE Press Book, Bellingham, Washington, 1997, p. 158.

Received November 7, 2015