PASSIVE-MATRIX LIGHT EMITTING MICRODISPLAY

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The construction, technology and main parameters of passive matrix light emitting microdisplay based on Schottky-structures of nanoporous silicon/aluminium for personal video projection system with improved properties were described. There functional control were realized visually with the aid of specially developed method and hard/software system installed on a personal computer using Windows XP operating system.

Keywords: Video projector, microdisplay, functional controller

Introduction

Presently, there had been a new interest with respect to microdisplay technology which started towards the end of the year 2013 by big corporations of the World such as Google, Microsoft, Samsung etc. This started when the corporations completed the development and commenced the production of a variety of <<smart eye glasses>> and mobile telecommunication devices based on a special technical component known as a microdisplay as shown in figure 1. Because of the fact that the distance of observation for a virtual image reproduced on a smart eye glass at a few centimeters corresponds to a full frame image on a bigger direct view, 40 inches television monitor at a distance of few meters as reflected in figure 2. It became clear that an image reproduction effectiveness of between 300-500 times can be achieved. Although the functionality of smart eye glass are defined by the software programme used, their required properties depends primarily on the parameters and characteristics used in their microdisplay.

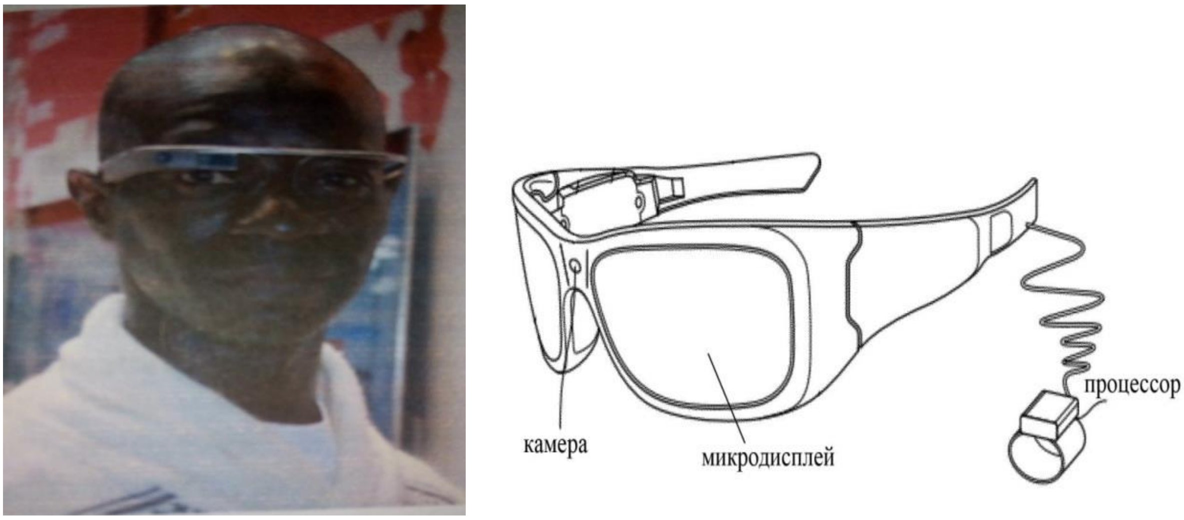


Figure 1. <<Smart>> eye glass (left) and Microsoft (right)

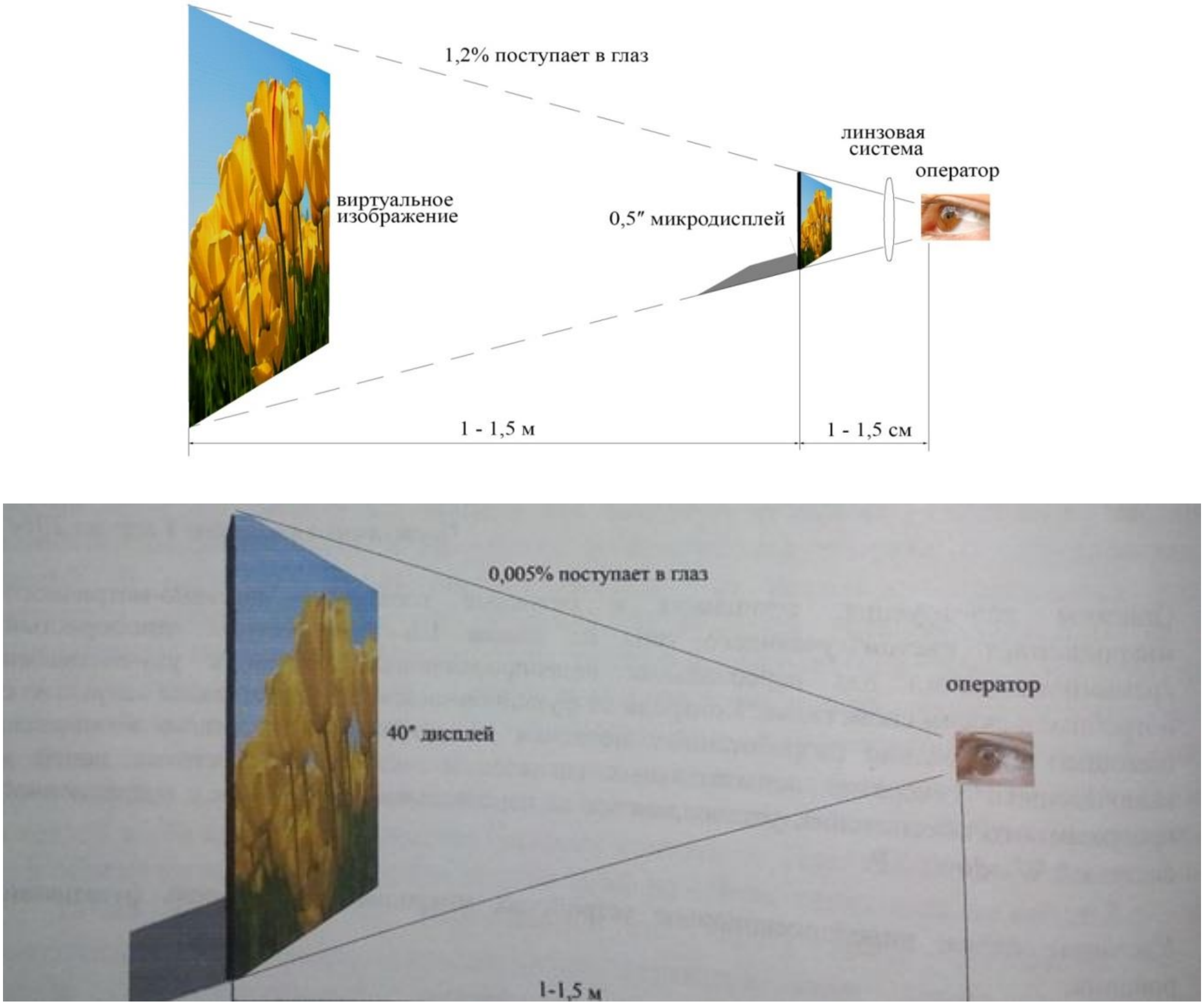


Figure 2. High efficient information display with the aid of microdisplay technology

The results of development of a passive matrix microdisplay light emitting type based on low electroluminescence Schottky structure , nanoporous silicon/aluminium are presented.

Electroluminescence in silicon with quantum efficiency of $\sim 10^{-8}$ was first obtained in the past 50 years. Furthermore it was established that creating massive quantum current or path can be achieved through self-forming silicon nanoporous structure using electrochemical process in a diluted ethanol acid solution which greatly improved the efficiency of the electroluminescence. Summary of this achievement was presented in [1].

Presently, the development of a reverse-biased diode based on nanostructured silicon resulted in a higher quantum efficiency of 1.4% which opened a new perspective for the development of full silicon high speed optoelectronic system of data transmission, high speed microdisplay etc. However, the physical processes for producing detailed structures are yet to be perfected, optimizing light emitting diodes is subjected to <<trial and error>>, thus obtained result cannot always be reproduced.

Passive matrix microdisplay with multiplexing control

Nanoporous silicon – a perspective material with possibilities of manufacturing fully integrated scheme of controlling microdisplay with higher functionality and reliability and higher ergonomical parameters and costs [2-4]. Microdisplay represented as matrix Schottky diode nanoporous aluminium/silicon effectively radiates in the visible range of the spectrum with an incident reverse voltage of a few volts. Their main advantages are:- minimal pixel sizes, higher resolution, and response time, usage in standard silicon CMOS- technology with backward compatibility which leads to lower cost with practically zero initial cost of investment in production base.

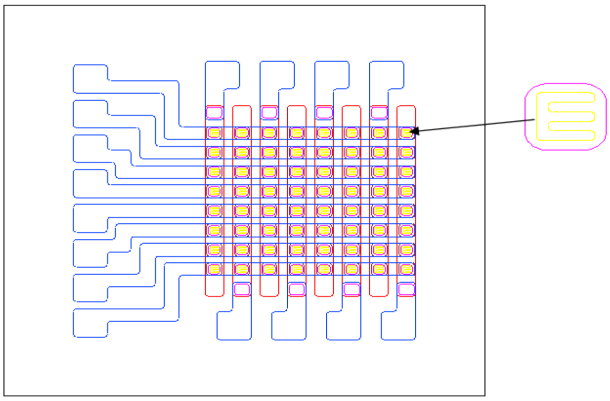


Figure 3. Topology of a microdisplay test sample

It has been observed that light emitting microdisplays (LED, OLED) have the following advantages over liquid crystal LCOS microdisplays;- much higher response time compared to liquid cystal cells which facilitate the development of higher information passive matrix microdisplay with higher image quality.

Lower response time and higher working current density facilitated effective multiplexing and thus the development of higher information passive matrix microdisplays. For instance, for current density J = 7000 A/cm^2 , active surface area A^2 = 0.6 x 0.6 cm, reverse voltage V = 8 V, external energy efficiency $\eta = 0.3\%$ *and radiation power* $W = 0.2\ MW$, its possible to achieve multiplexing level, M = (J.V.η.A^2)/W = 30,2400, which corresponds to Video Graphic Array (VGA) format of microdisplay resolution. For 10µs addressing cycle, response time of each pixel must then be $\sim$ 30 ns, which can easily be achieved in silicon light emitting diodes. At such level of multiplexing, direct reflection of video information can be accomplished without additional micro scheme memory and usage of special drivers.

In the Scientific Research and Development Laboratory (4.7) of BSUIR for creating highly stable silicon reverse-biased light emitting diodes we traditionally used Al-Al_2O_3 electrode systems on surfaces of nanoporous silicon. Technologically, this system consists of depositing aluminium and then anodizing through photoresist mask.

And its distinct advantages are:-

- lower temperature process;
- vacuum cleaner layers of porous silicon during preparation and deposition of Al;
- full isolation of porous silicon from external reaction of Al-Al_2O_3 layers.

During the process of development and fabrication of test sample of silicon passive-matrix microdisplay based on nanoporous silicon, problems associated to light emitting element were resolved (increased breakdown voltage, <<dead>> current in the initial portion of the ampere-brightness characteristics, radiation outputs around the electrode perimeter) in addition to those peculiar functions of passive-matrix display (such as problems of current leakages to individual light emitting diodes through narrow length of wheel, problems of frame radiation and varying volt-brightness characteristics, problems of creating bigger quantity of point connectors for controlling passive matrix etc.) external cross sectional view of the test sample of silicon and active structures are shown in figures 4 and 5 respectively.

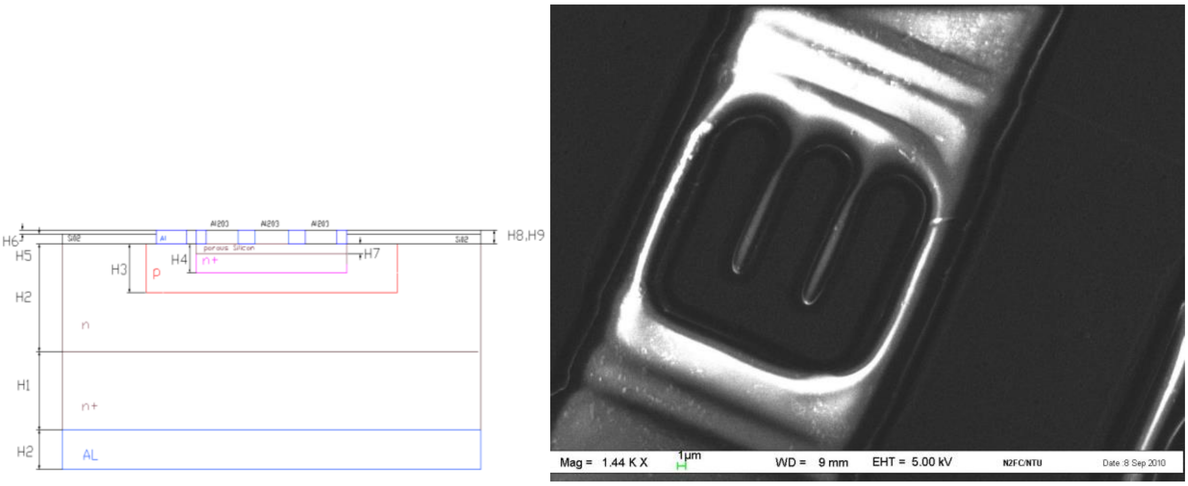


Figure 4. Active structure of test sample of microdisplay crystal

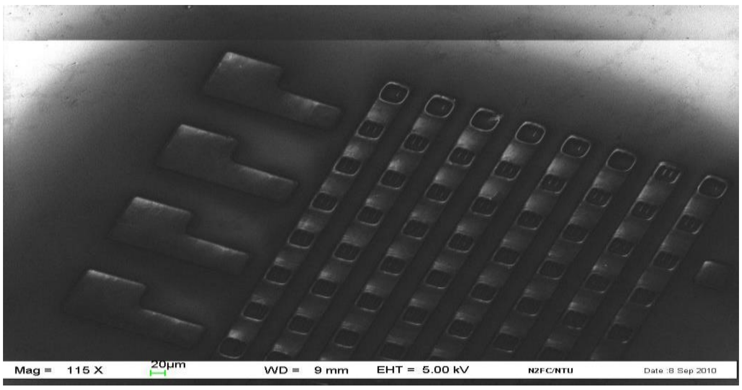


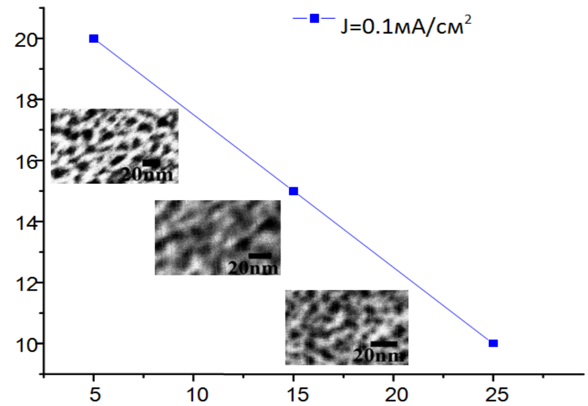
Figure 5. External view of microdisplay crsytal

Main features of the given structure are:- usage in the form of upper electrode Schottky diode, special formation of nanoporous silicon as functional layer for light emitting devices possessed of transparency of 65-70% [5,6] and low electrical resistivity 100 Ωm/KV, which substantially increases the working efficiency of the device.

Technology of Nanoporous silicon layer formation

Standard technological method for the formation of nanoporous silicon as a functional layer for light emitting optoelectronic devices is electrochemical etching (anodization) in concentrated hydrofluoric acid solution. But this method has some disadvantages such as:- short anodizing time (few seconds for thin porous layer formation; higher toxicity for operators and aggressive reaction of hydrofluoric acid on metallization. In this work, for the formation of a stable and reproducible layers of nanoporous silicon, we for the very first time used diluted solution of hydrofluoric acid composed of $NH_4F:H_2PO_4:C_2H_5OH:H_2O$ with minute concentration of fluorine ions. Addition of ethanol (C_2H_5OH) enabled effectively moistened the silicon surface, as a result of which reproducibility process increased and addition of phosphor acid (H_2PO_4) enabled controlling the level of fluoride ions in the solution thus achieving uniform pore size layers. While the application of Ammonium nitrogen (NH_4F) reduced the level of toxicity to absolutely safer level for operators and also minimizes the aggressive reaction on the metallization of the device.

The dependence of pore sizes in the solution $NH_4F:H_2PO_4:C_2H_5OH:H_2O$ on the concentration of NH_4F at a current density of $J= 0.1$ mA/cm^2 is shown in figure 6. Evidently, with an increase in NH_4F concentration from 5 to 25 weight % pore sizes decreased from 20 to 10 nm. The porous layers have spongy structures and porosity range of 70-80% figure 5.



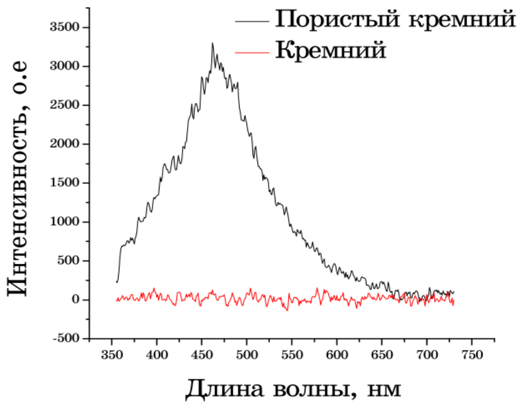


Figure 6. dependence of pore size on concentration NH_4F in solution of $NH_4F:H_2PO_4:C_2H_5OH:H_2O$

Figure 7. Spectrum of photoluminescence of nanoporous & monocrystal silicon

The photoluminescence spectrum of nanoporous and monocrystal silicon are shown in figure 7. As seen from the figure, peak photoluminescence for nanoporous silicon lies in the blue region (460 ns)

Technological optimization process

The sequential technological process of fabricating a test sample of crystal matrix microdisplay light emitting type based on nanoporous silicon combined with standard CMOS technology.

Technological chart and main structural parameters

Element structure	Thickness	Type of conductor	Material used	Surface resistance	Resistivity
Name			Name		
Substrate H1	255± 20	n	Antimony alloying agent	-	0.01
Epitaxial layer H2	13± 1.5	n	Phosphor alloying agent	-	3.0 ±0.3
Base H3	3.2± 0.5	P	Flavour	250±50	-
Emitter H4	2.0 ±0.8	n	Pure Phosphor trichloride	3-7	-
Oxide H5	0.7± 0.07	-	Silicon dioxide	-	-
Protective layer H6	0.2 – 0.27	-	Tetraethoxysilane, Three methyl esters phosphoric acid	-	-
Etched Si in n-portion H7	0.4-0.6	n	Solution $NH_4F:H_2PO_4:C_2H_5OH:H_2O$ in different ratios	-	-
Metallization H8	1.0-1.2	-	Al ingots	-	-
Etched Al H9	1.0-1.2	-	Solution of $H_2SO_4:H_2O$	-	-

Results of the radiating structure:

- minimal spatial resolution 12 x 12 μm;
- operating voltage from -5 to -8 V;
- response time from 5 to 30 ns;
- current density 7000 A/cm^2;
- brightness of radiation not less than 20 C/m^2;
- external efficiency not less than 1%;
- life time not less than 7000 hr.

Thus, passive matrix microdisplay based on silicon avalanche diode could be very competitive with respect to video projector system personal type.

Conclusion

The construction, technology and main features of passive matrix light emitting microdisplay based on reverse baised Schottky diode with nanoporous Si/Al structures had been described. Special attention was devoted to the formation process of nanoporous silicon layers required thickness which had high porous spongy structure with nano pore sizes that enabled its efficient usage in a variety of light emitting optoelectronic devices.

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