# SILICON BASED COLOR PHOTOSENSITIVE CELLS WITH DEEP COLOR SEPARATION ON $P^{+}$-P JUNCTIONS: CONSTRUCTIVE AND TECHNOLOGICAL DESIGN PROBLEMS

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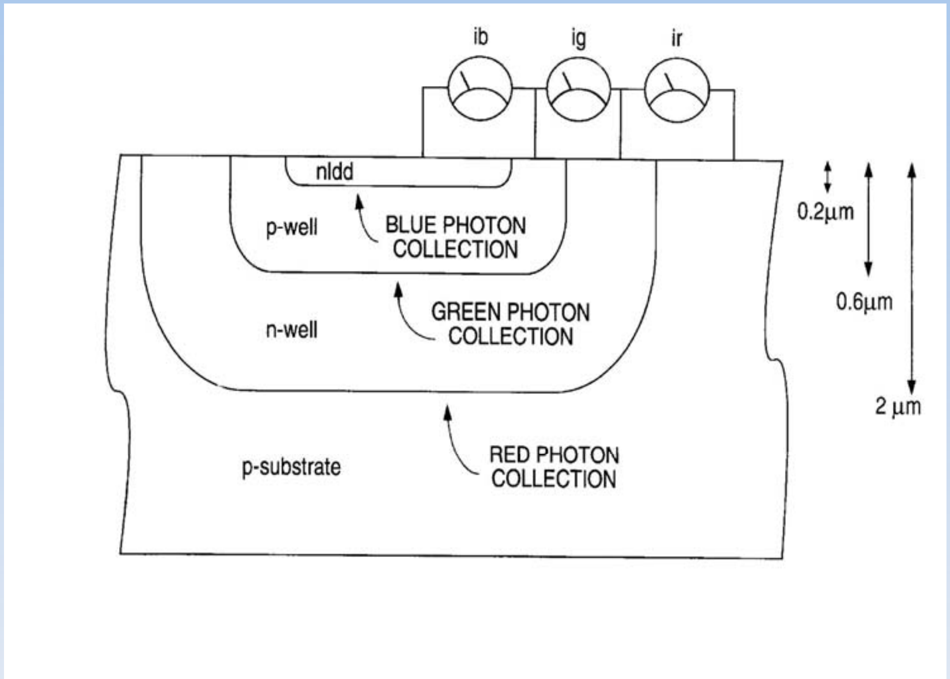
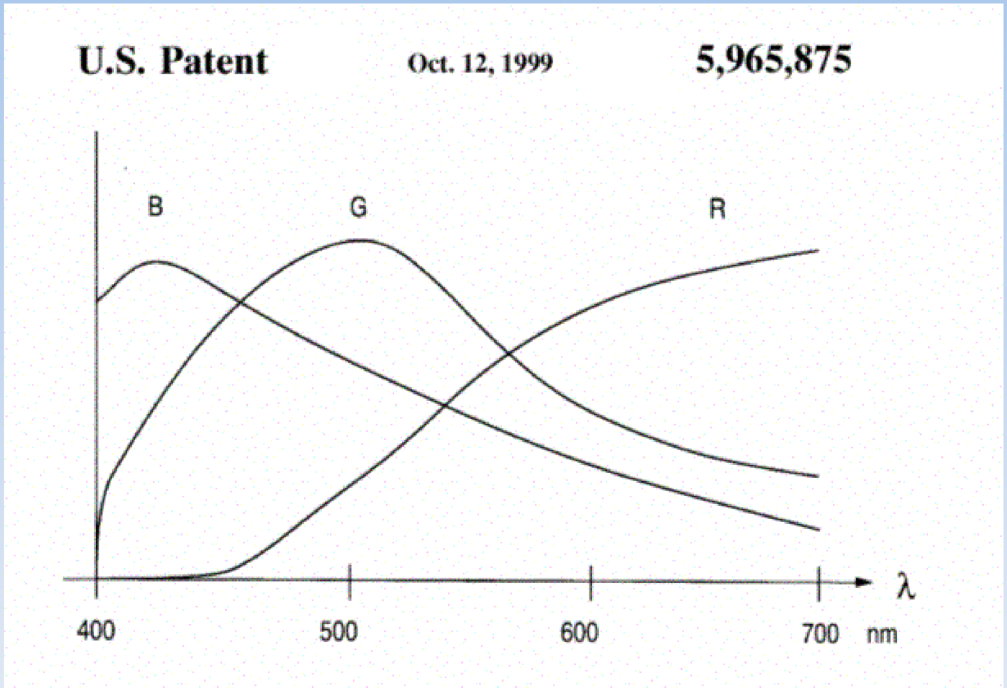
# 2 Photo current separation process between three color components in the single *Foveon* photocell

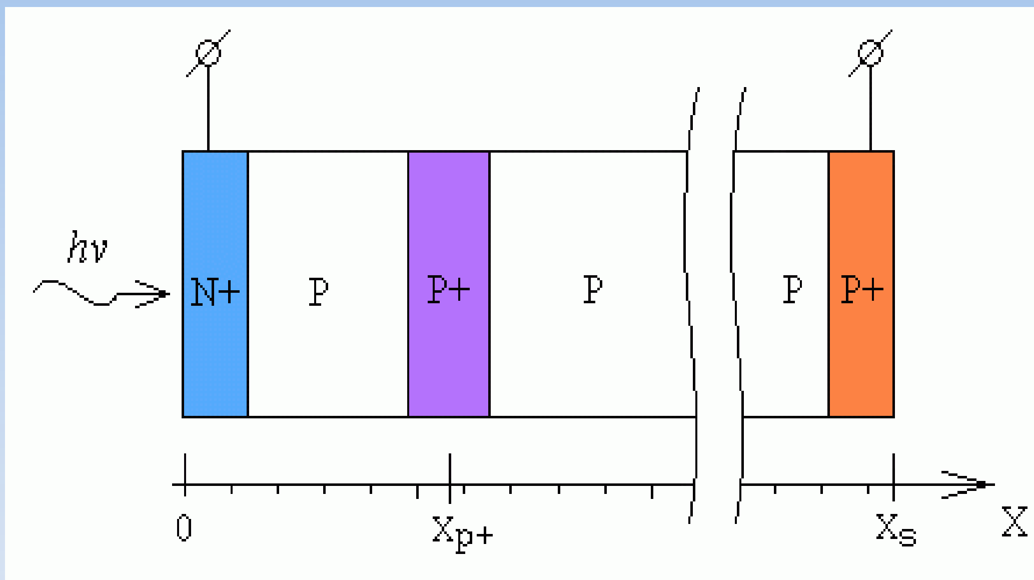



a) photocell structure

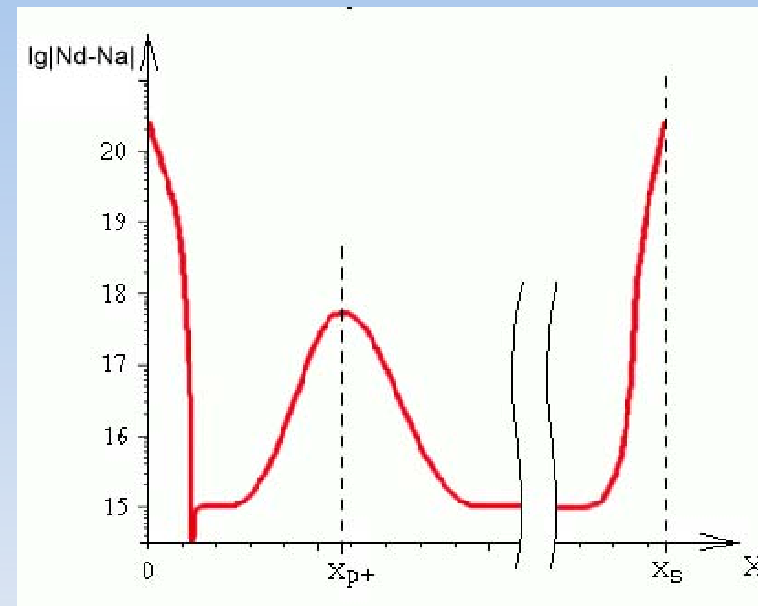



b) photocell color channels spectral sensitivity

# P+-P barriers potential



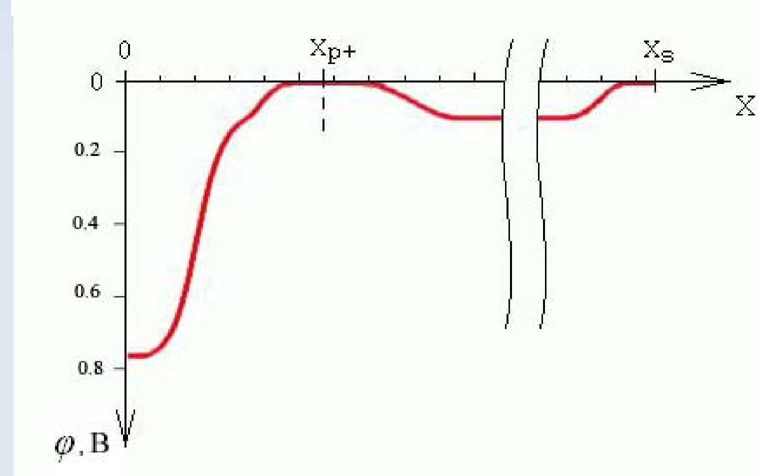

a)




b)

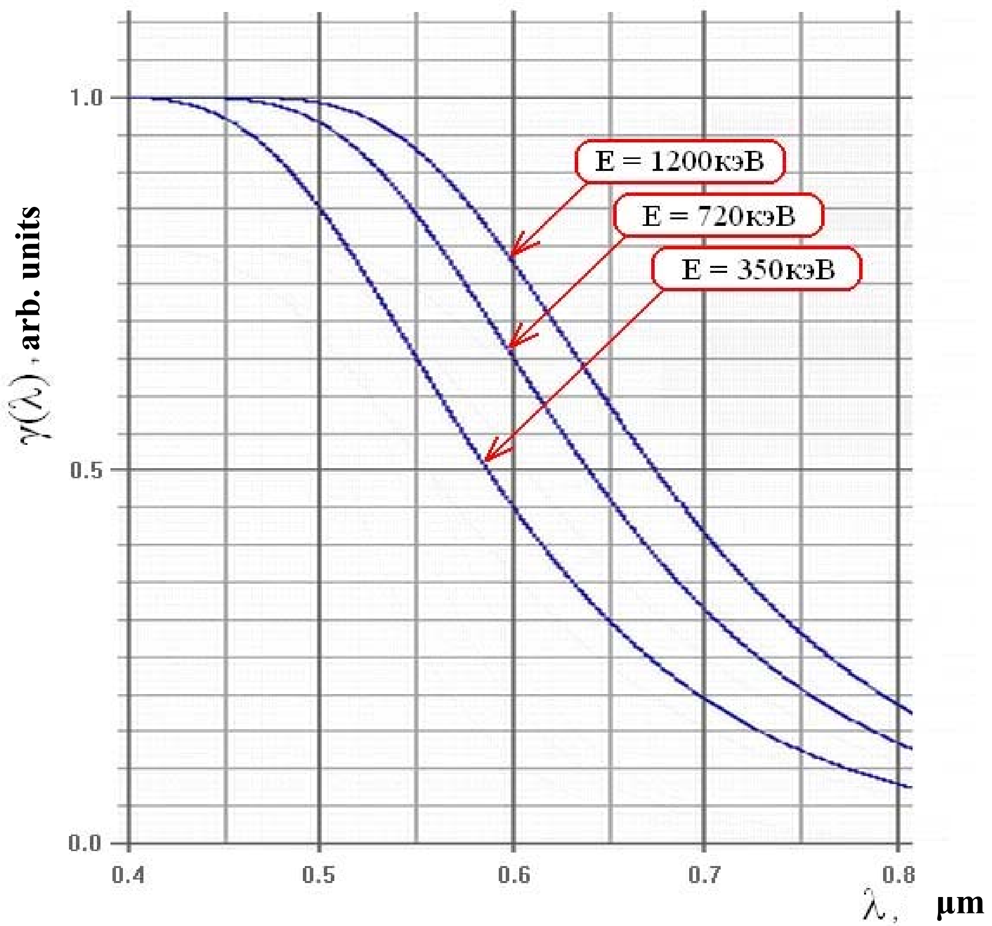
$$-\frac{d}{dx}\left[-D_n\frac{dn}{dx}+\mu_n\frac{d\varphi}{dx}n\right]=\frac{n-n_0}{\tau_n}-I_0\alpha(\lambda)\exp\left(-\alpha(\lambda)x\right) \quad (1)$$

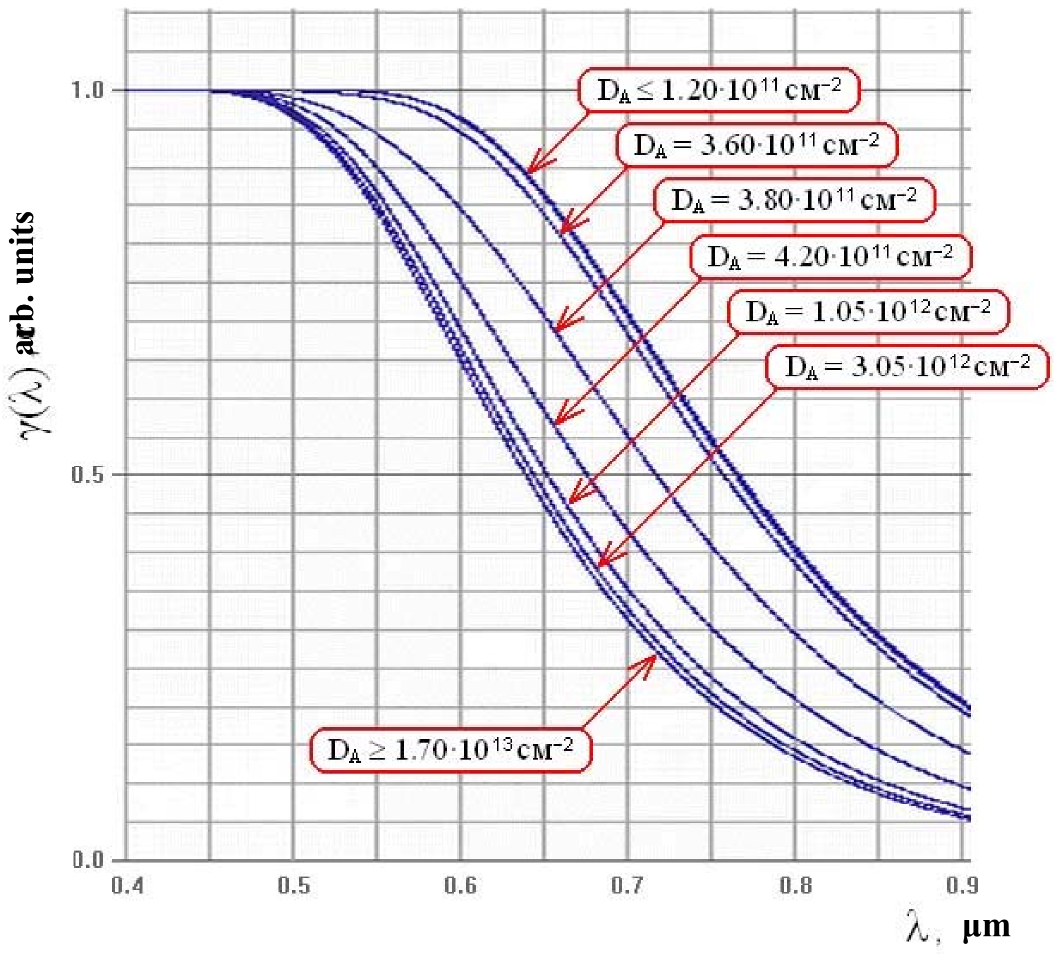
$$\varphi(x)=-\frac{kT}{q}\ln\frac{p_0+N_A(x)}{p_0} \quad (2)$$




c)

# 4 Analytical quantum spectral sensitivity γ(λ) curves of the photo sensitive structure

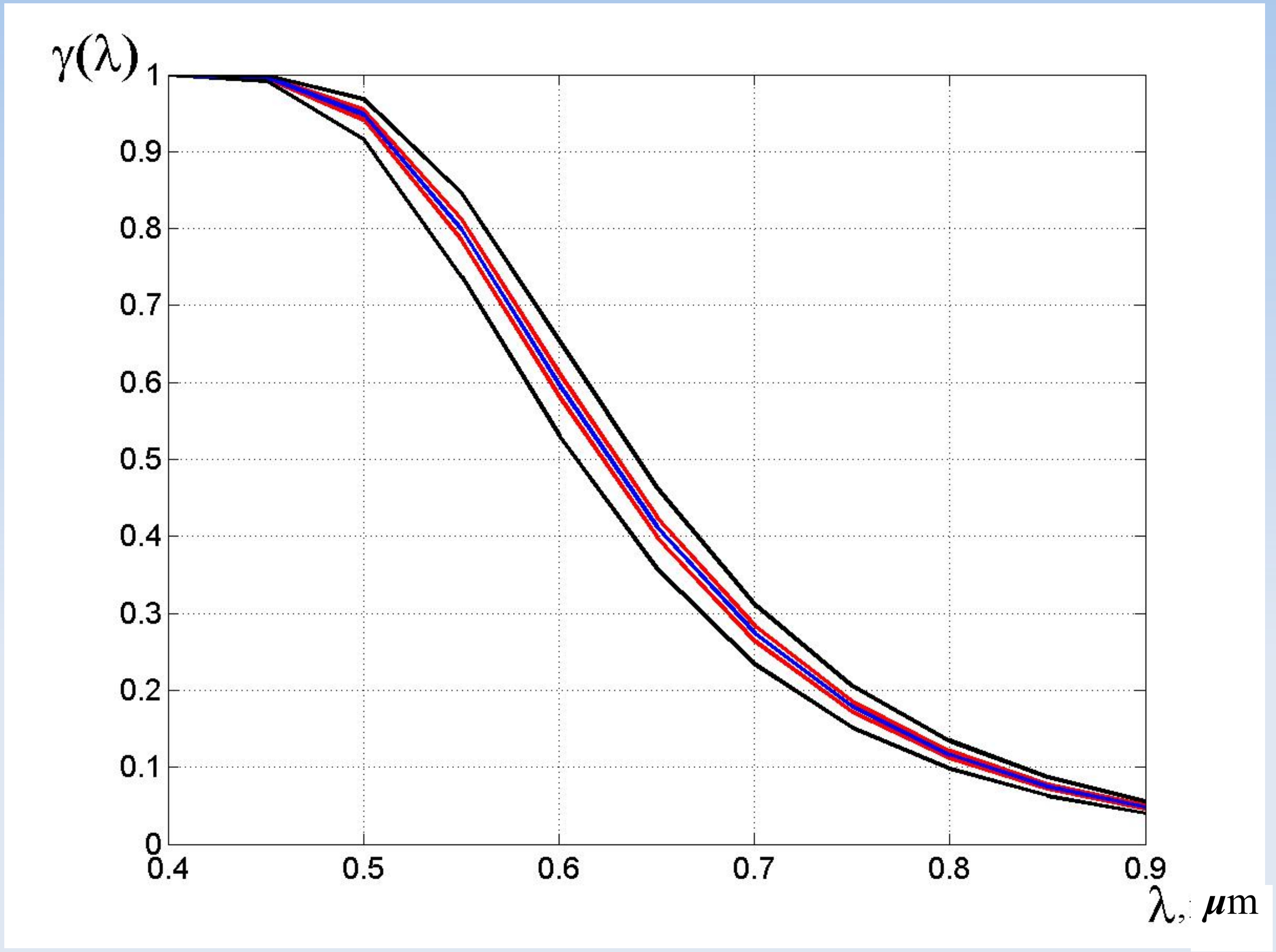



a) Different implantation energies E with the same p+ implantation dose $D_A$ ~$1.70*10^{13}$см$^{-2}$

b) Different $p^+$ implantation doses $D_A$ with the same implantation energy E = 720 keV

# Analytical quantum spectral sensitivity $\gamma(\lambda)$ curves for *n-p-n* and *p-p*$^{+}$*-p* structures with process energy dispersion

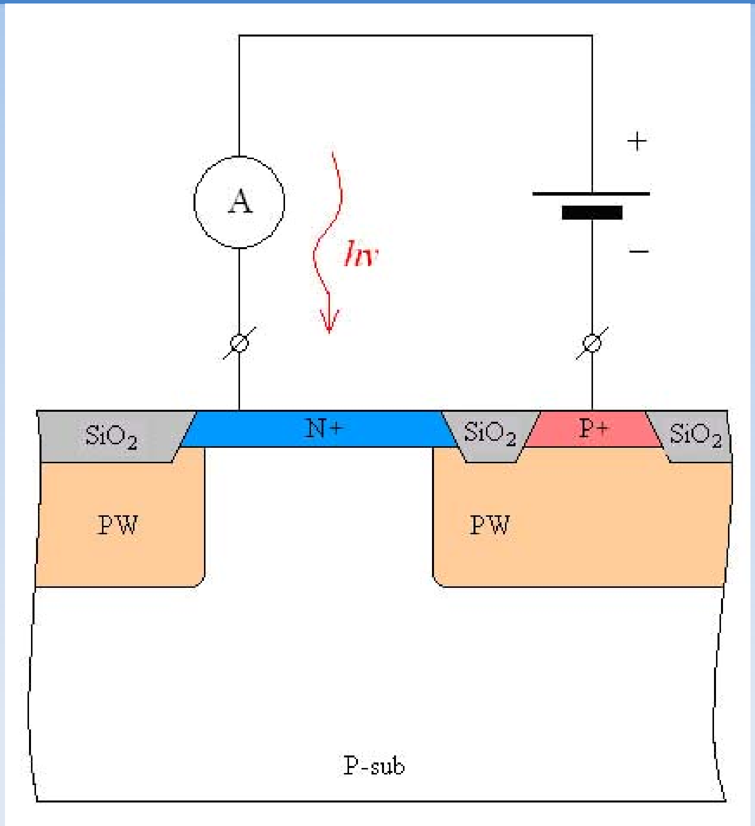



***Black***: *p-n* junction, ***red***: $p^{+}$-$p$

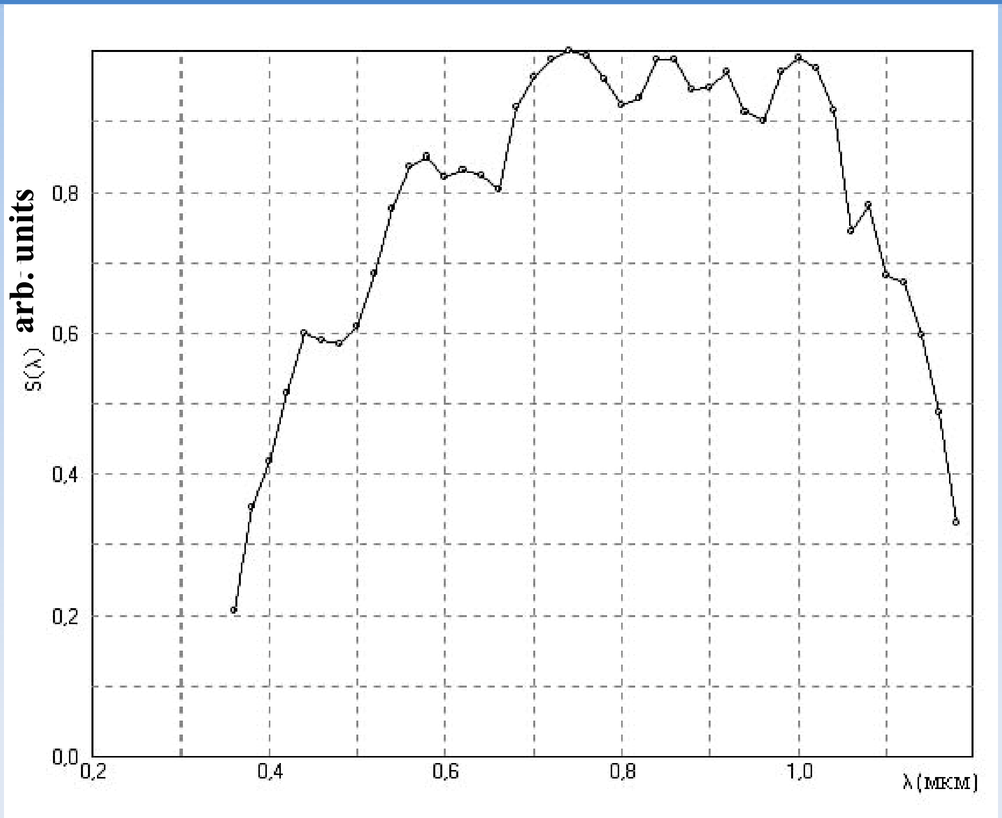
# 8 bit color tables

| colors from the photocells | on isotype p-n junctions | Standart color | on p-n junctions |
|---|---|---|---|
| violet | 130 41 220 | 138 43 226 | 180 30 240 |
| blue | 2 0 238 | 0 0 255 | 14 20 205 |
| cyan | 126 192 238 | 135 206 235 | 116 185 210 |
| green | 10 250 0 | 0 255 0 | 40 210 5 |
| yellow | 249 245 0 | 255 255 0 | 240 230 0 |
| orange | 250 160 12 | 255 165 0 | 205 102 30 |
| red | 250 3 0 | 255 0 0 | 230 12 6 |

# Basic $n^+$- $p$ photodiode

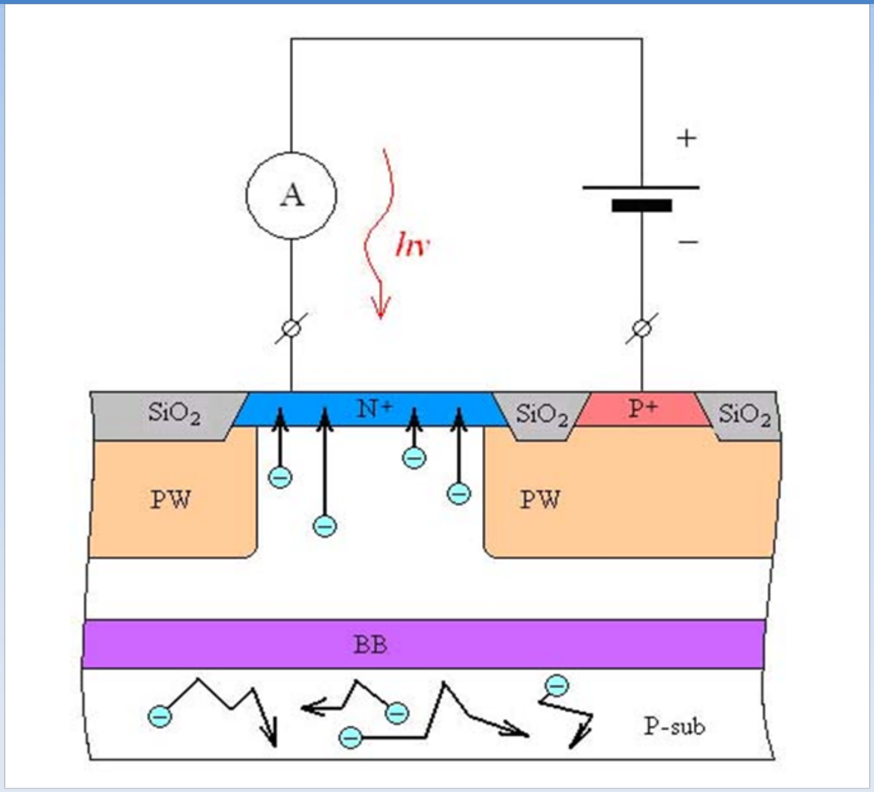



a) Structure

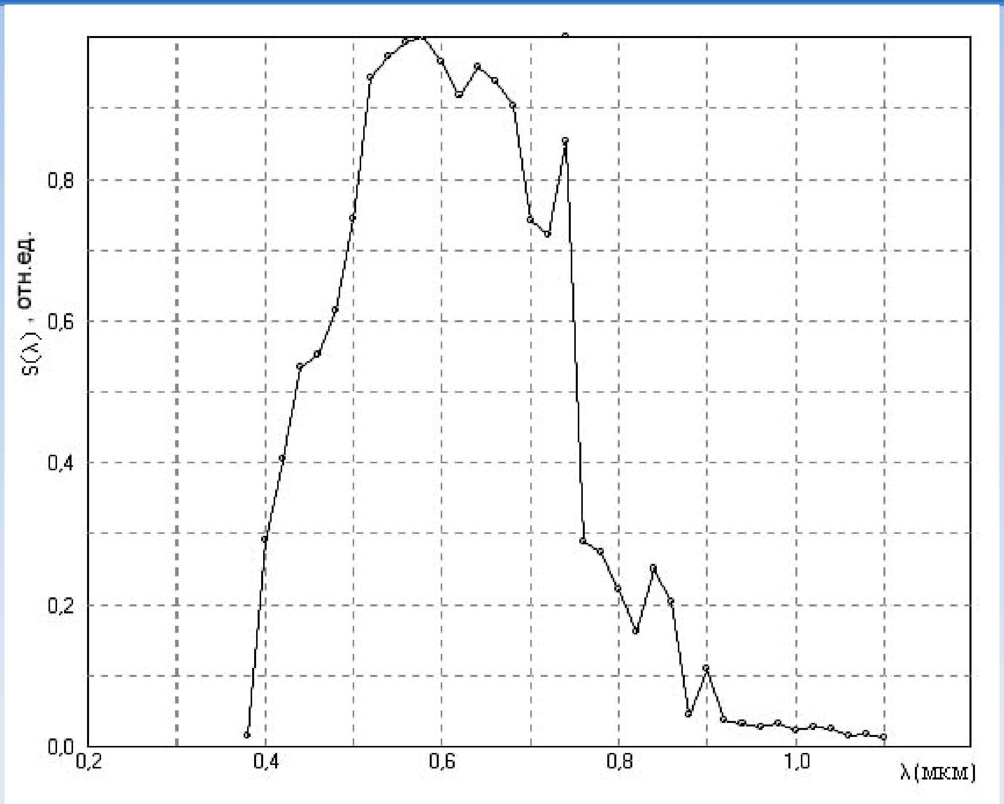



b) Spectral sensitivity

# 8 Boron distribution profile in asymmetric silicon $n^+$-p photodiode




a) Structure with implanted $p^+$ layer




b) Spectral sensitivity

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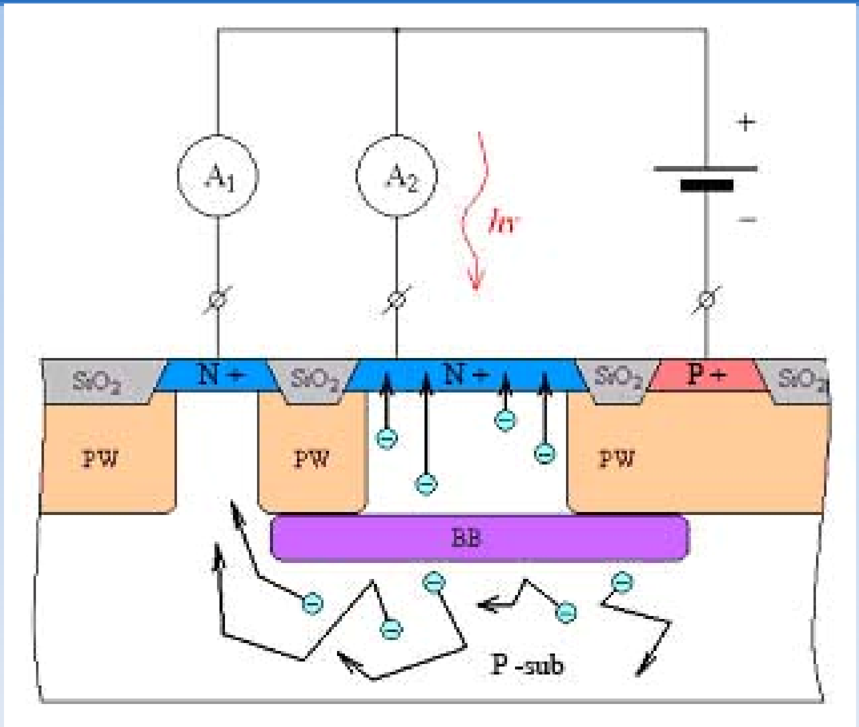
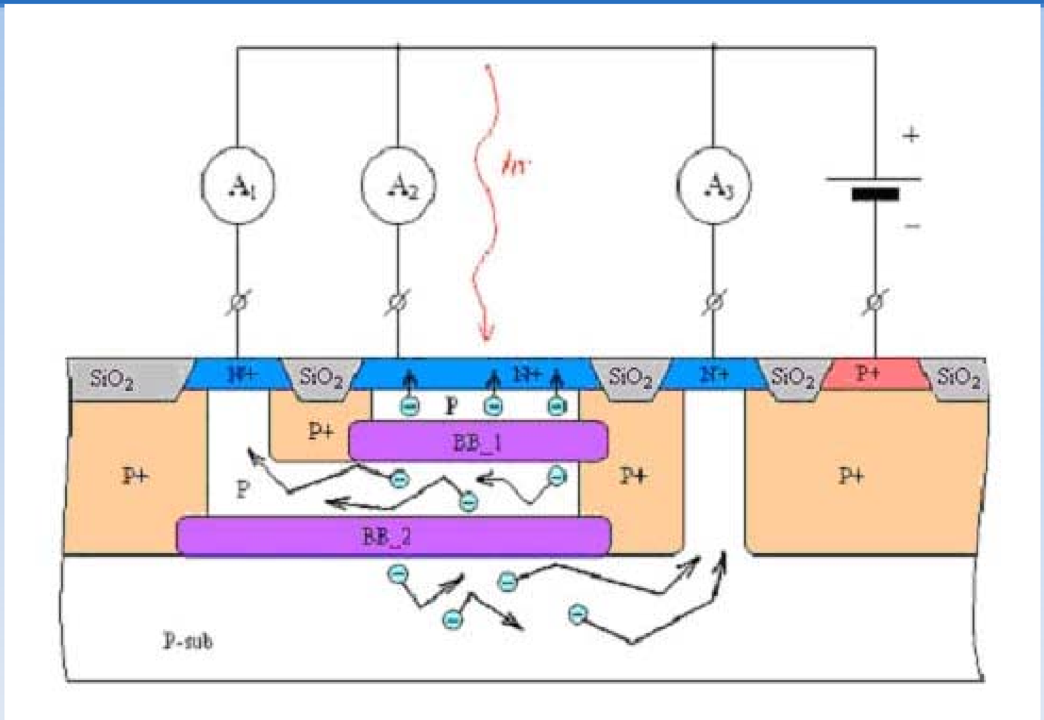
# Proposed approach of several spectral components integration on the single photocell

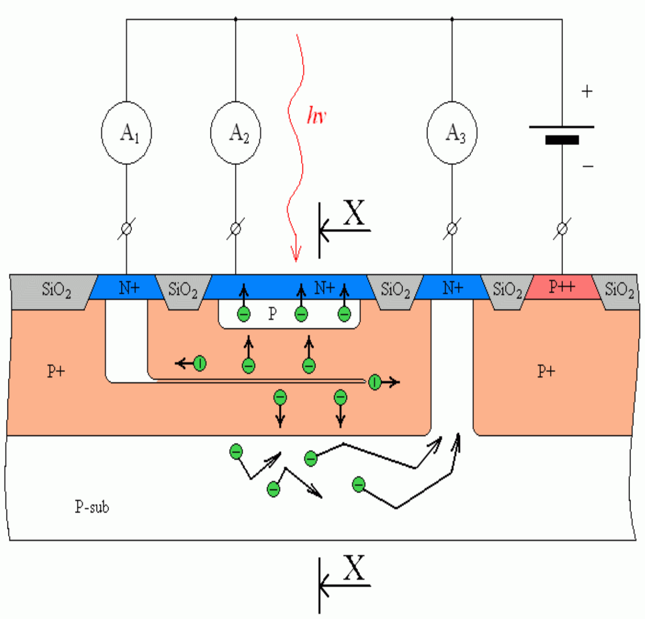



a) Two colors photocell

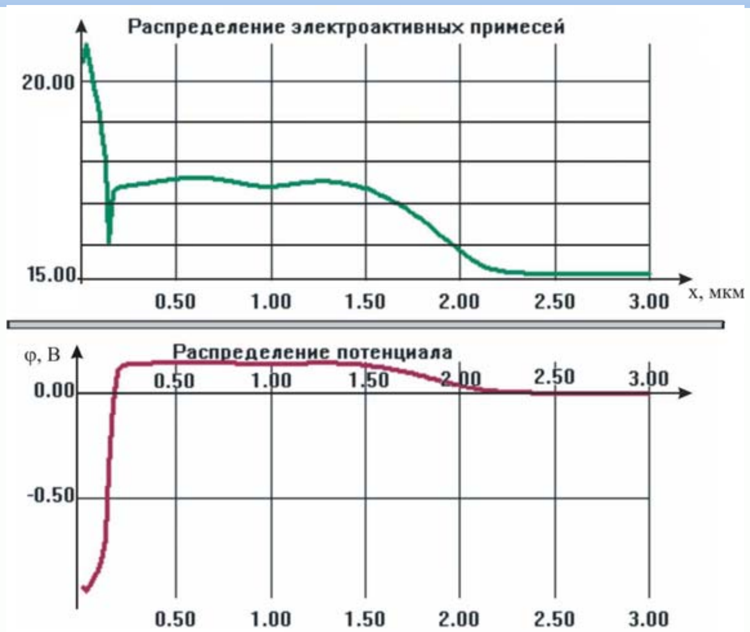



b) Three colors photocell

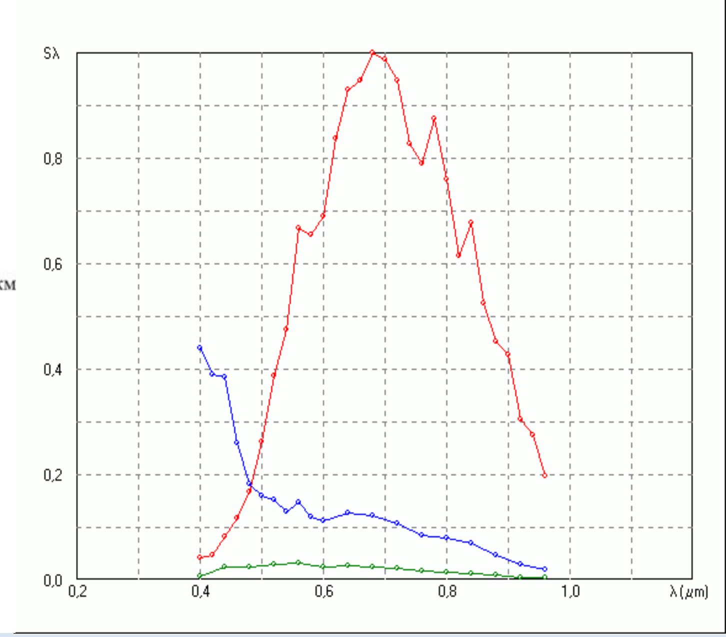
# "Blue-green" and "green-red" barrier p+ layers generation. Barrier layers joint




a) Three-contacts photocell structure with barrier layers joint

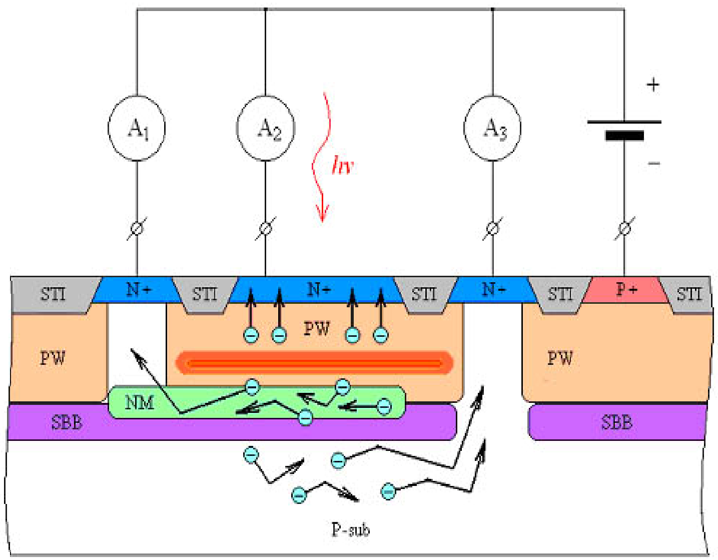


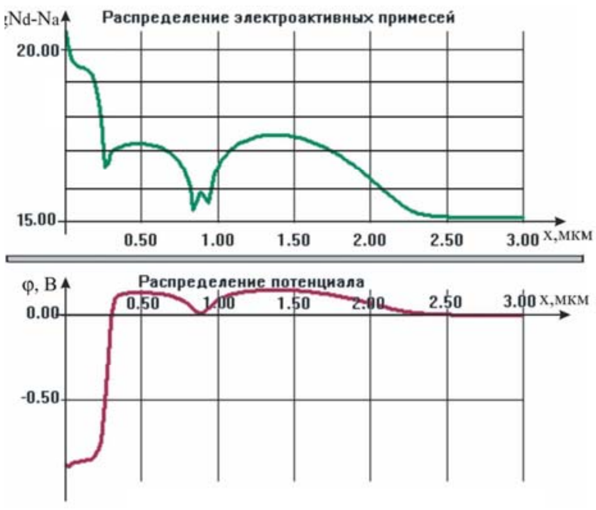

b) Analytical distributions of electro-active impurities and potential

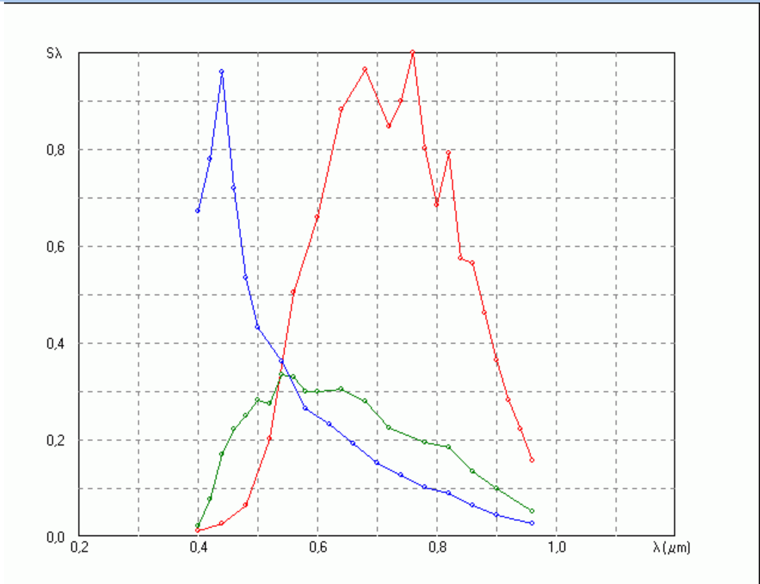



c) Three colors spectral sensitivity curves measured in the case of barrier layers joint

# Barrier layers joint elimination




a) Three-contacts color photocell structure with n$^{-}$ compensation

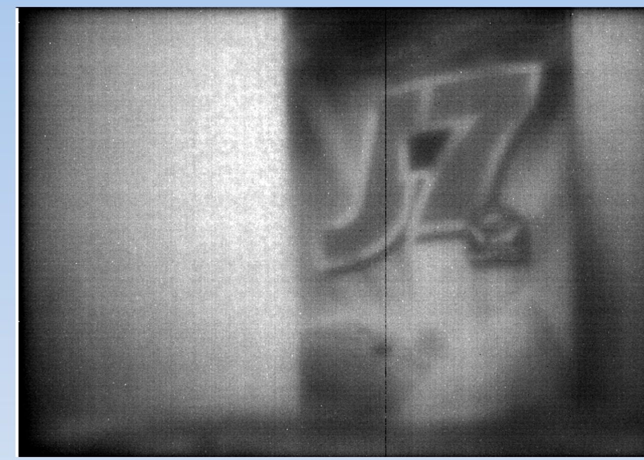
b) Analytical distributions of electro-active impurities and potential

c) Three colors spectral sensitivity curves measured in the case of n$^{-}$ compensation

# Photo matrix resolution upgrade directed to decrease IR sensitivity.
# Photocell with deep color separation in epitaxial p-layer on p- substrate

a)


b)

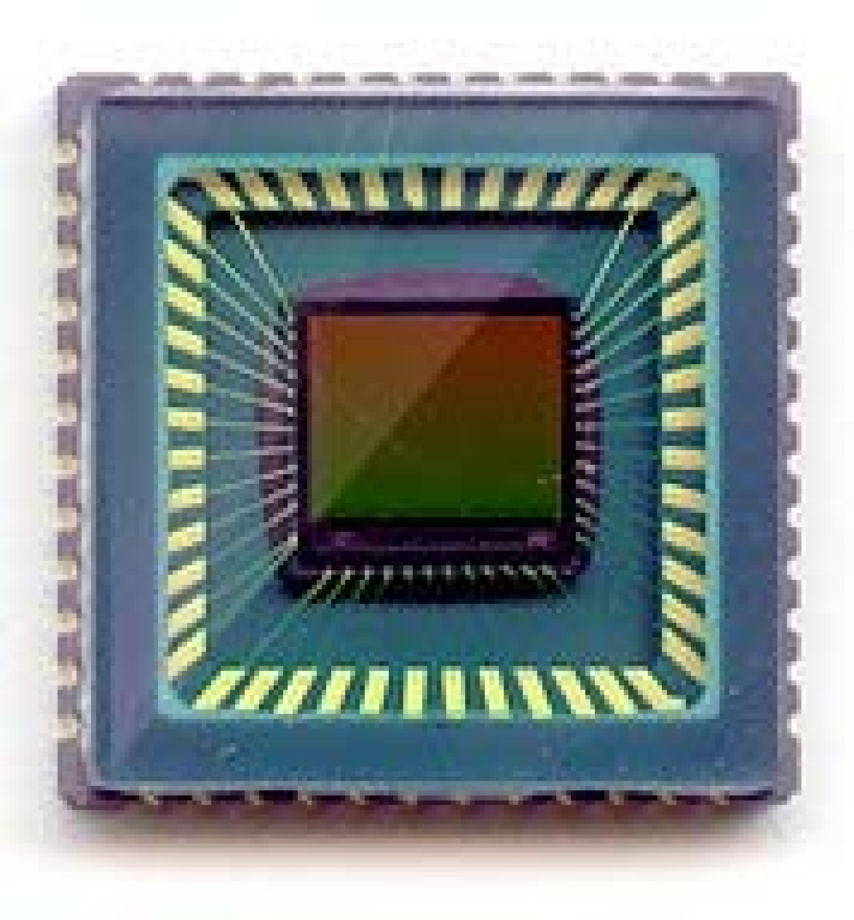


c)


d)

Images obtained with test devices, where in p-substrate was formed:
(a) – green channel, (b) – red channel;
in epitaxial p– layer on p– substrate: (c) – green channel, (d) – red channel

# True color photo matrix with resolution 640x512



Crystal mounted in the case

# Photographs obtained with proposed color photo matrix with resolution 640x512

# Results

1. In the present work it is demonstrated that for effective color separation in the silicon based photo receivers can be used isotype p+-p energy barriers instead of opposite p-n junctions. These barriers are formed by layer implantation with two orders difference of the concentration magnitude.

2. The vertical integration of "red", "green" and "blue" photo sensitive elements is formed with lateral electron diffusion in p+-p-p+ channels which provides effective electron pathway to the remote n+ contacts.

3. The effective color photocell spectral sensitivity optimization is provided by the variation of the barrier layers depth. The quantum spectral sensitivity dispersion is measured to be 12% for p-n junction, and three times less (4 %) for isotype p+-p junction. These results are obtained in the case of technology process implantation energy dispersion which resulted in color separation border depth drift for 0.1*10-6 m.

4. It is found that depth distance between barriers the most critical parameter for the green color part of the spectra. It is proposed to apply compensative n-layer to eliminate p+ layers joint.

5. It is proposed to apply epitaxial substrates or p+ barrier layer for the photo matrix IR sensitivity reduction.

6. The presented results describe integration of the high-resolution silicon based photo reciever, image reading and processing schematics on the single crystal manufactured with the standard CMOS technology process.