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TEST OF MICROPIXEL AVALANCHE PHOTODIODES

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Исследование микропиксельных лавинных фотодиодов

Микропиксельные лавинные фотодиоды (МЛФД) — новые фотодетекторы с микропиксельной внутренней структурой на общей кремниевой подложке. Типичный размер каждого пикселя 20–30 мкм, плотность около 10^3 мм$^{-2}$. Каждый пиксель работает в режиме Гейгера на общую нагрузку. Разряд ограничивается индивидуальным гасящим резистором, включенным в каждую цепь питания пикселя (отрицательная обратная связь, как у газового счетчика Гейгера) и размещенным на общей подложке. В режиме Гейгера можно получить коэффициент усиления для единичных фотоэлектронов на уровне 10^6 при комнатной температуре. Измерены и сравнены усиление, эффективность регистрации фотонов, однофотоэлектронное разрешение, шум и темновой ток для разных типов МЛФД.

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Test of Micropixel Avalanche Photodiodes

The micropixel avalanche photodiode (MAPD) is a novel photodetector with a multipixel intrinsic structure on the common silicon substrate. The typical size of each pixel is 20–30 μm and the density is about 10^3 mm^{-2}. Each pixel works on the common load in the Geiger mode, where the discharge is limited by an individual quenching resistor (negative feedback like in the gas Geiger counter) included in each pixel feeding chain located on the common substrate. In the Geiger mode one can get an amplification factor for a single photoelectron at the level of 10^6 at room temperature. Measurements of gain, photon detection efficiency, one-photoelectron resolution, noise and dark current for different types of MAPD were performed and compared.

The investigation has been performed at the Dzhelepov Laboratory of Nuclear Problems, JINR.

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The micropixel avalanche photodiodes (MAPD) is a novel photodetector with a multipixel intrinsic structure on the common silicon substrate. The typical size of each pixel is 20–30 μm and the density is about 10^3 mm^{-2}. Each pixel works as independent photon microcounter on the common load in the Geiger mode, where the discharge is limited by an individual quenching resistor (negative feedback like in the gas Geiger counter) included in each pixel feeding chain located on the common substrate. Actually, each pixel operates digitally «yes/no» in response to an incident photon, but MAPD in the whole is an analogue device, which can measure the light intensity within the dynamic range corresponding to the total number of pixels.

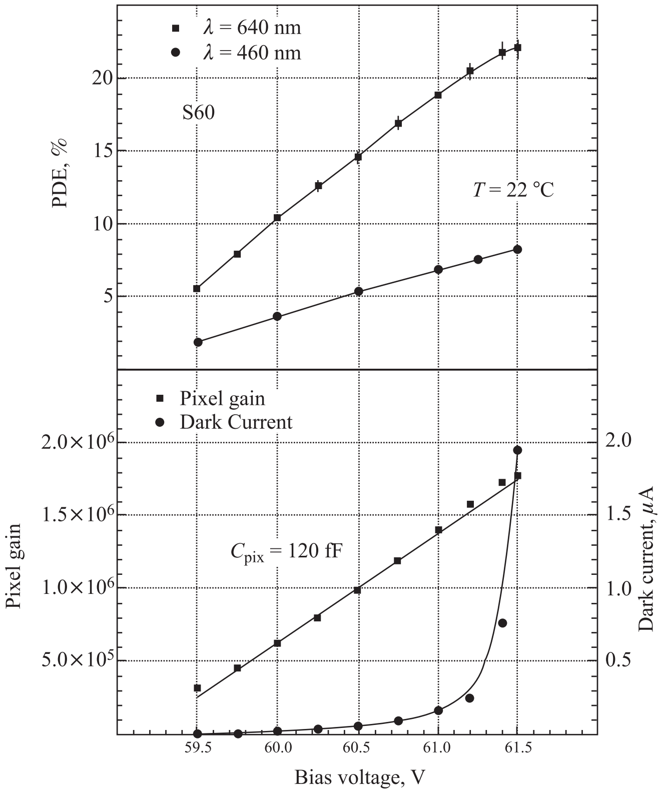

Fig. 1. Pixel gain, PDE and dark current versus bias voltage for S60

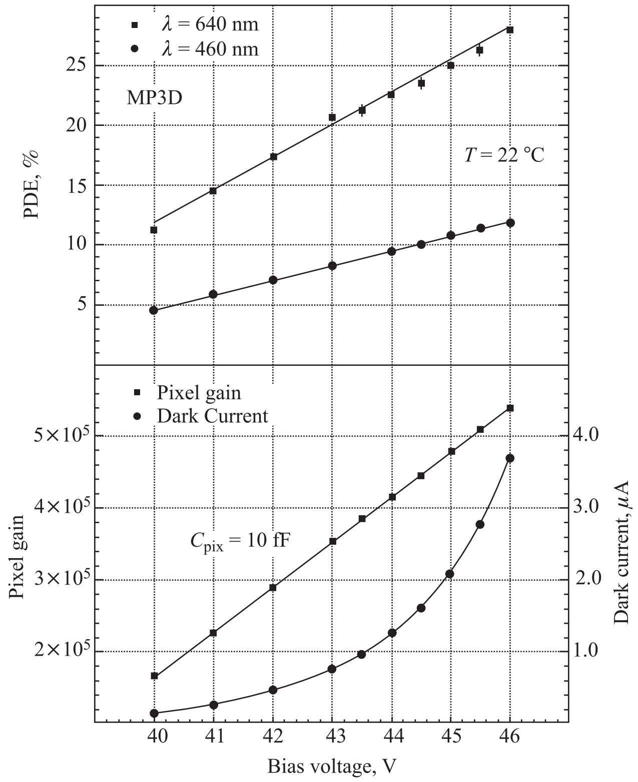

Fig. 2. Pixel gain, PDE and dark current versus bias voltage for MP3D

The basic design of MAPD with individual vertical quenching resistor has been proposed in Russia in 1989 [1]. This design has disadvantages, low sensitivity in blue and in the UV range of the spectrum due to absorption in the resistive layer and low production yield because of the short circuit effect through the thin vertical resistive layer.

The next design of MAPD with individual surface drift charge channels [2] and with individual surface resistor [3, 4], at least partially avoids the above disadvantages.

We study three different types of MAPD: S60 with individual surface drift charge channels, MP3D with individual surface resistors designed by Z. Sadygov [5] and SSPM-050701GR-TO18 commercial device available from Photonique, SA in Switzerland [6].

The MAPD S60 and MP3D consist of about 1000 pixels and SSPM-050701GR-TO18 consists of 556 pixels. All devices are produced on the low resistive p-type silicon substrate and have 1 mm^2 of total area.

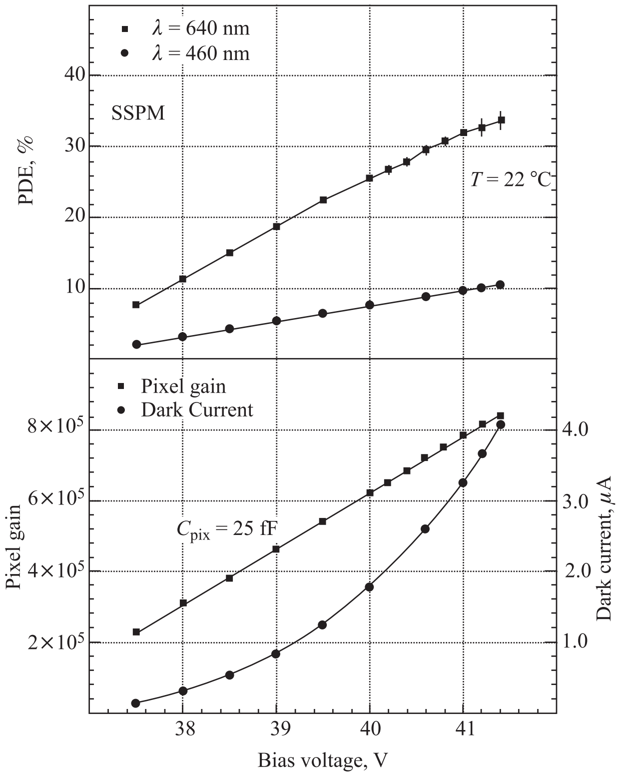

Fig. 3. Pixel gain, PDE and dark current versus bias voltage for SSPM-050701GR-TO18

The MAPD performance was studied at room temperature by means of a fast LED with the use of low-intensity light flashes [7].

Figures 1, 2, 3 show the MAPD single pixel gain, dark current, photon detection efficiency (PDE) for different light wavelengths depending on bias voltage. The experimental points for pixel gain have been obtained by measuring the single-photoelectron peak position (see Fig. 4). The MAPD gain is proportional to the effective capacitance of the pixel times the overvoltage. The function's slope of pixel gain from bias voltage corresponds to effective pixel capacitance. The different types of MAPD have various capacitance C_{pix} (see Figs. 1, 2, 3).

The PDE is a product of quantum efficiency QE of the sensitive area and geometrical factor ε_{g} (ratio of sensitive area to total surface) and the probability P_{tr} that an incoming photon triggers an avalanche breakdown:

$$\text{PDE} = \text{QE} \cdot \varepsilon_{\text{g}} \cdot P_{\text{tr}}.$$

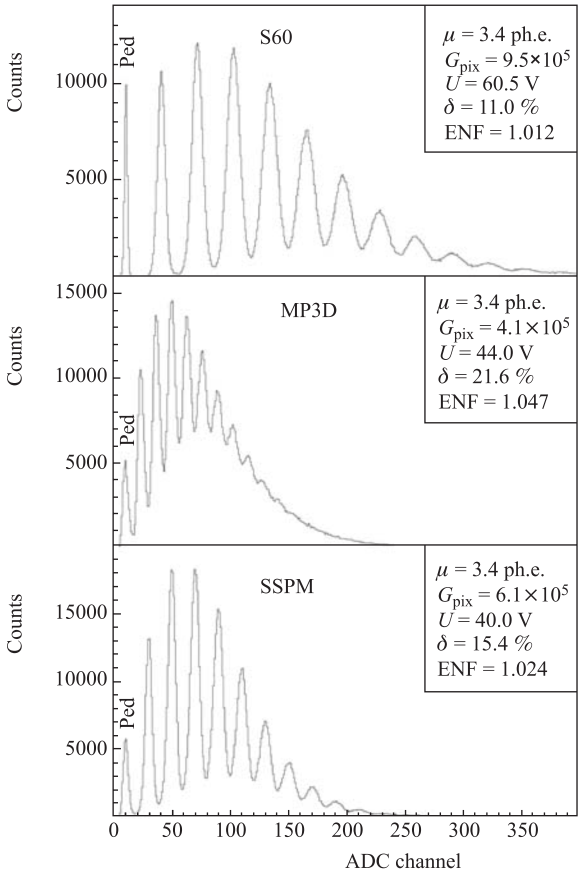

Fig. 4. Typical LED spectra of MAPD for low-intensity light pulses with mean number of 3.4 ph.e. at $T = 22$ °C

The PDE rises with the increase of bias voltage as a result of increment of triggering probability $P_{\rm tr}$, apparently due to effects of high electric field [8]. The $\varepsilon_{\rm g}$ is about 50% for S60, MP3D and approximately 70% for SSPM-050701GR-TO18.

All devices have high single electron resolution δ and excellent excess noise factor ENF [7] (see Fig. 4).

The electronic noise of MAPD is small due to high gain and, therefore, level of electronic noise is less than 0.2 electrons (see Fig. 4, pedestal width). The main source of dark noise rate (dark current) is a breakdown triggered by generation of thermal free carriers in sensitive volume. Figure 5 shows the dark count rates as a function of the threshold in units of amplitude signal from fired pixels by any

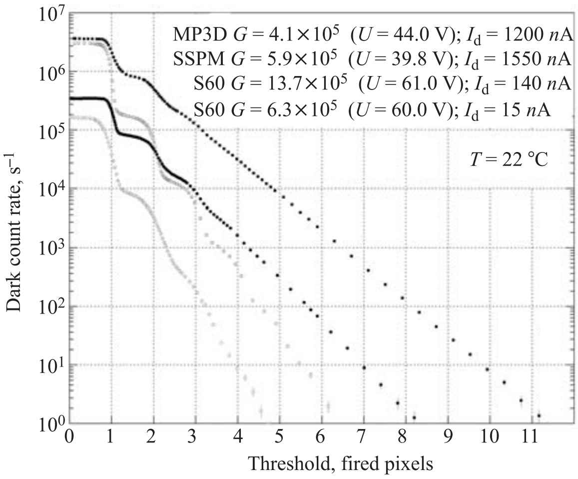

Fig. 5. The dark count rate of the MAPD for different gains in dependence on the threshold

generation of free carriers. The dark noise rate depends on design and production technology of MAPD and limits MAPD performance only in detection of small light intensities (few photoelectrons), and it does not affect in the case of large light signals.

Investigations of MAPD show that S60 holds much promise due to high gain, excellent single-electron resolution and low dark count rate.

In conclusion, we would like to thank Dr. Z. Sadygov for providing us with samples of MAPD and for useful discussions.

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