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MODERN CCD SENSORS APPLIED IN IMAGING SPECTROMETERS

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Abstract

In the paper, the state-of-the–art tendencies for design and construction of CCD types of sensors and their usage in spectroscopy applications is considered. The main performance characteristics of such devices when operating in imaging spectrometers on-board aircraft or satellites are highlighted and the requirements regarding their operating conditions are discussed. The experimental results obtained in the process of laboratory testing are shown and the basic CCD types are described.

1. Introduction

CCD (charge coupled device) sensors are widely applied in some scientific areas, such as spectroscopy, astronomy, etc. As a rule, these applications' operation modes involve device performance under low light illumination and limited integration time depending on the craft trajectory temporary characteristic [1, 2]. This fact imposes severe requirements towards their basic characteristics. The most important characteristics of CCD detectors when operated in imaging spectrometers are response, resolution, readout noise, dynamic range.

As a rule, in spectroscopy applications, CCD detectors are combined with a proper optical system to create a spectral image. A CCD can simultaneously collect spectrally dispersed light over a wide range at high speed. The two-dimensional CCDs used in such systems enable simultaneous measurement and analysis at multiple spectra from several spatial sources.

2. Basic CCD characteristics

Spectral response. The spectral response of CCD sensors is determined by the quantum efficiency. It is wavelength-dependent, because the absorption coefficient of silicon is wavelength-dependent. The absorption coefficient is approximately zero at wavelength shorter than 400nm and wavelength longer than 1100nm. The maximum of the quantum efficiency depends on geometrical and technological parameters and usage materials.

Dark current. The term "dark current" comes from the fact that the current is generated equally well in complete darkness. Depending on where in the silicon unwanted electrons are generated, some of the charges will collect in the CCD wells and, jointly with signal-generated electrons, will form output signal.

Dynamic range. Another important characteristic of the CCD, when operating in low–light conditions is its dynamic range. It may be defined as the ratio of the largest measurable useful signal to the smallest detectable signal. The smallest detectable signal is limited by the readout noise. The largest signal depends on full-well capacity.

3. Type of CCD sensors

Most modern scientific spectroscopy applications use two-dimensional full-frame- or frame-transfer CCD detectors, which are photo-sensitive across their full active surface area. A variety of devices are available, including front-illuminated devices, back-illuminated devices, virtual phase technologies, etc.

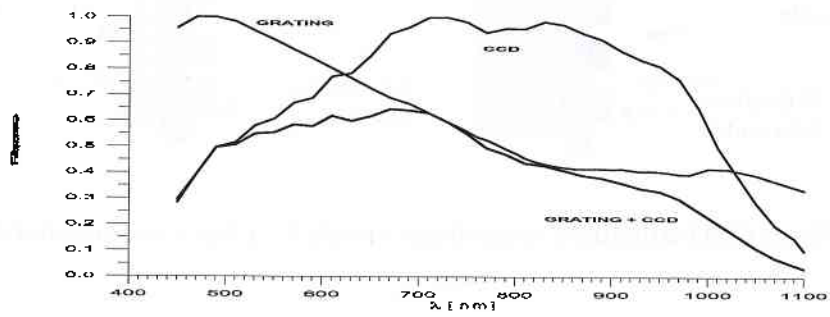

Fig. 1 Spectral response characteristic of CCD 221 (Fairchald)

Conventional CCDs are less sensitive (Fig. 1) compared to recent devices, because part of their surface area is coated with non-transparent electrodes [3].

Another type of front-illuminated CCDs are large-format, full-frame detectors, These devices are photosensitive across their full active surface area, because the gates, placed over the sensitive area, are typically composed of semi-transparent polysilicon (Fig. 2 – left). These sensors accommodate long exposure times. They offer the lowest dark current of all available sensor technologies and produce the best signal-to-noise ratios in low-light condition. Their light sensitivity, high charge capacity and low dark current also deliver a very large dynamic range. Unfortunately, polysilicon gates absorb or reflect incident light at wavelengths below 500 nm and the trade-off for large sensing areas has reduced sensitivity at shorter wavelengths (Fig. 3 – KAF1400) [4].

A type of CCD that offers a higher UV (ultra-violet) sensitivity is the so-called front-illuminated UV CCD, in which the detector is coated with phosphor, or the sensors with indium oxide gates, a material which is more transparent than polysilicon at short wavelengths (Fig. 3 – KAF1401E).

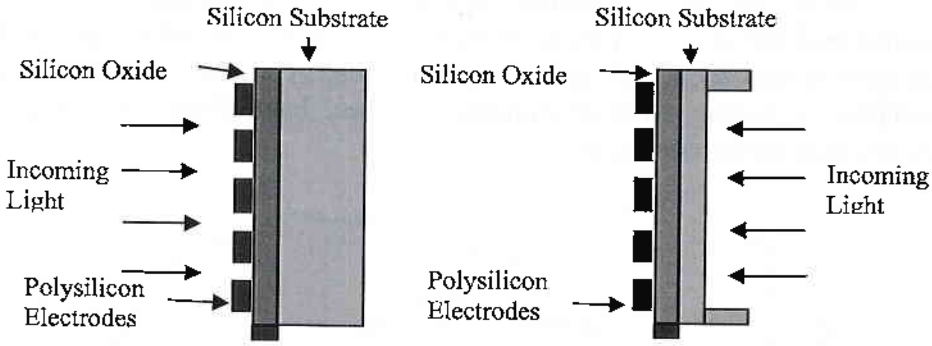

Fig. 2 CCD structures: front-illuminated (left), back-illuminated (right).

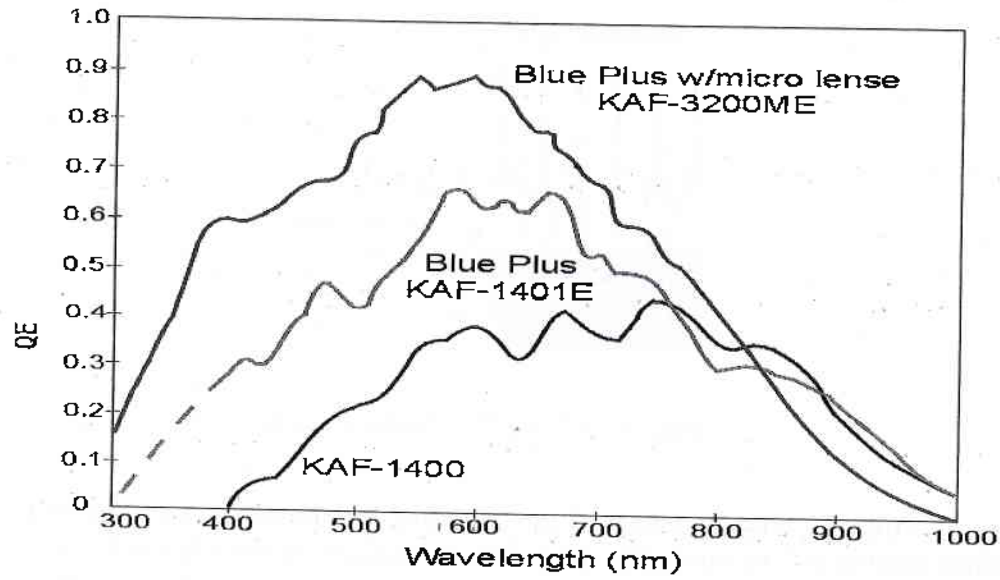

Fig. 3 Spectral response characteristics of KAFxxxx (Kodak) CCDs [4].

Another type of CCDs, using microlens array to direct light to photosensitive area, have improved efficiency over the whole spectral range (Fig. 4). This approach does not sacrifice other performance parameters. [5].

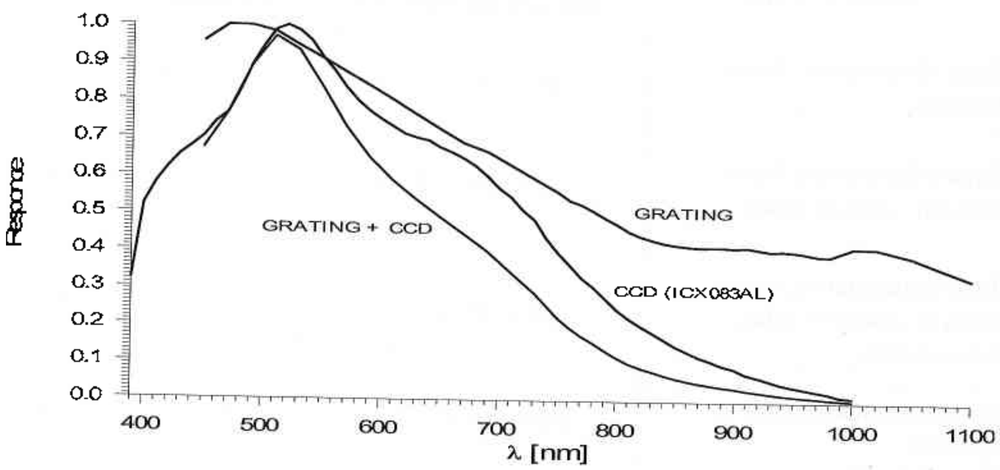

Fig. 4 Spectral response characteristic of ICX083AL (Sony) CCD

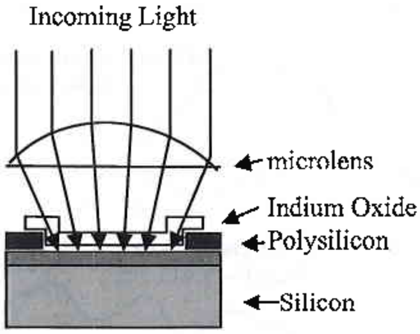

Fig. 5 CCD KAF3200ME structure

Another type of CCDs (Fig. 5), ,using a combination of the two above-mentioned technologies (the use of indium oxide electrodes and microlenses) have dramatically improved efficiency over the whole spectral range (Fig. 3 – KAF3200ME). These combined changes raised the peak quantum efficiency to 85 percent, a level previously possible only to back-illuminated sensors

Table 1.

Sensors' Type	**Quantum Effisiency 400 nm max 800 nm**	**Dark Current**	**Price**
front-illuminated, frame transfer	0% 45% 35%	*	*
front-illuminated, frame transfer, indium oxide	30% 65% 30%	*	**
front-illuminated, frame transfer, indium oxide, microlenses	60% 85% 45%	*	**
back-illuminated, frame transfer	65% 90% 75%	***	***

Legend: * - low, ** - midle, * - high**

They also improved quantum efficiency for blue and NIR (near-infra-red) regions.Back-illuminated CCDs, in which the substrate is thinned (Fig. 2 – right), feature enhanced response in the UV and the NIR regions (Table 1). Back-illuminated CCDs are much more expensive than their front-illuminated counterparts because they are difficult to make. These devices often require liquid nitrogen cooling to reduce noise. They have large pixel sizes, which limits resolution.

An additional comparative review of CCD types and their most important characteristics is shown in Table 1.

4. Conclusions

New sensor technologies offer many types of CCDs appropriate to low-light applications, including imaging spectrometers on-board aircraft or satellites. There are two-dimensional, large-format, frame transfer, front-illuminated or back-illuminated CCD sensors.

The choice of the CCD sensor is related to the application's requirements. In general, the choice should be made based on the spectral range, resolution, the expected optical signal levels, and the type of the constructed imaging spectrometer, such as ground-based, airborne or space-borne system. These requirements determine the chip type, total active area, number of pixels, pixel size, etc.

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СЪВРЕМЕННИ CCD ПРИБОРИ, ПРИЛОЖИМИ ВЪВ ВИДИОМЕТРИЧНИ СИСТЕМИ

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Резюме

В работата са разгледани съвременните тенденции в развитието и изграждането на CCD прибори от гледна точка на приложимостта им във видеоспектрометрични системи. Посочени са специфичните условия на функциониране на сензорите и произтичащите от тях изисквания към по-важните им характеристики и параметри. Показани са основните типове прибори и е направена сравнителна оценка на техните характеристики. Приведени са експериментално получени резултати от изследвания на различни типове CCD сензори.