

Charge Coupled Devices (CCDs) requiring enhanced performance in the Near Infrared (NIR) region of the spectrum or at higher X-ray energies can benefit from being constructed on specially selected silicon with an optimised thickness. Such a CCD, where the electron generation is within this thick silicon, is known as a Deep Depletion Device (High Resistivity).

Introduction

'Deep depletion' devices are variants of certain standard e2v technologies products fabricated on different silicon material to increase the quantum efficiency at near-IR wavelengths and with higher energy X-rays, but without loss of spatial resolution.

Basic principles

The depth over which photons generate signal charge in the silicon beneath the CCD electrode structure increases with increasing wavelength, the consequences of which are shown schematically in Fig. 1. Front and backside illuminated devices are shown. Fig. 2 also shows the variation of absorption coefficient with wavelength.

Frontside illuminated devices

At visible wavelengths the charge is largely generated within the depletion region beneath the electrodes and the probability of charge being collected in the 'correct' pixel (i.e. the pixel on which the photon was incident) is high. This is because there is an electric field in the depletion region normal to the silicon surface that causes the charge to move directly to the nearest potential well in the buried channel for subsequent storage. However, at longer wavelengths much of the generation can be deep in the field-free silicon below the depletion region and charge can diffuse (in a random manner) away from the point of generation before being attracted to the depletion region of a pixel for storage. The probability of being collected in the correct pixel is therefore reduced, and this loss of spatial resolution is usually defined in terms of increased pixel cross-talk or reduced Modulation Transfer Function. Similar effects are observed with high energy X-rays.

In order to minimise this effect most devices are now made on 'epitaxial' silicon. This material comprises a heavily doped substrate on which is deposited a more lightly doped surface layer, the parameters of which can be controlled in manufacture. The heavy doping in the substrate considerably reduces the distance any photo-generated charge can diffuse before it recombines, with the result that almost none of it is collected as signal. The substrate is therefore effectively 'dead', and device performance is dependent on the properties of the 'active' epitaxial layer. Detailed analysis suggests that, for most applications, a reasonable compromise between quantum efficiency and resolution is for the thickness to be comparable to the pixel pitch and 20 to 25 μm is typically used for e2v technologies devices of standard manufacture.

Backside illuminated devices

In this case, the total thickness of silicon is thinned to typically <20 μm and longer wavelengths can pass through this thickness. This means that long wavelengths (e.g. >800 nm) are not efficiently absorbed.

The introduction of deep depletion silicon

A few specialised applications do however require highest possible quantum efficiency at NIR wavelengths or higher X-ray energies and, for a given device structure, this can only be achieved by increasing the active thickness, as now described.

So far the analysis has not considered the depth of depletion in the silicon below the electrodes. Although device performance would obviously benefit if this could be increased, various practical constraints exist to limit the depth to no more than about 10 μm (which is adequate for 20 to 25 μm total layer thickness)

The actual depth of depletion is proportional to (V/N_A) , where V is the channel potential and N_A is the doping concentration of the silicon below the buried channel. V is generally set by the range of normal operating voltages, and N_A cannot easily be reduced below a certain minimum value through dopant out-diffusion from the underlying heavily-doped substrate, hence the current limit. However, with careful optimisation of the deposition conditions, epitaxial silicon can be obtained with considerably reduced doping concentrations, thus permitting the total layer thickness to be increased to nominally 50 μm with a depth of depletion of at least 30 μm . These high resistivity devices fabricated on such material are designated 'deep depletion'.

Frontside and backside illuminated devices are manufactured with deep depletion silicon. Both devices benefit from improved red response, whilst the backside illuminated devices can deliver improved overall quantum efficiency and better blue response.

Performance

Figure 3 shows measurements made on frontside CCD15-11 devices to illustrate the improvement in near-IR quantum efficiency possible with deep depletion devices over that available with standard products. The spatial resolution of the two variants is similar, as are the operating voltages and all other parameters, e.g. full well capacity, output responsivity, noise etc.

Figure 4 indicates performance of backside-illuminated devices. One curve indicates the QE of a normal silicon 'astro broadband' device (as used on many large area astronomy sensors). The other curve indicates QE of deep depletion silicon, process with the standard midband AR coating.

Note that the spatial resolution of deep depletion devices can degrade when fast optics are used if the cone of light extending into the silicon from a focused spot generates charge directly beneath adjacent pixels. This is simply a consequence of active depth being greater than the pixel pitch, and standard devices may be preferable for such applications.

Also, since we consider that cosmetic quality of deep depletion silicon is somewhat poorer, a differing cosmetic specification may be applied for devices of this material.

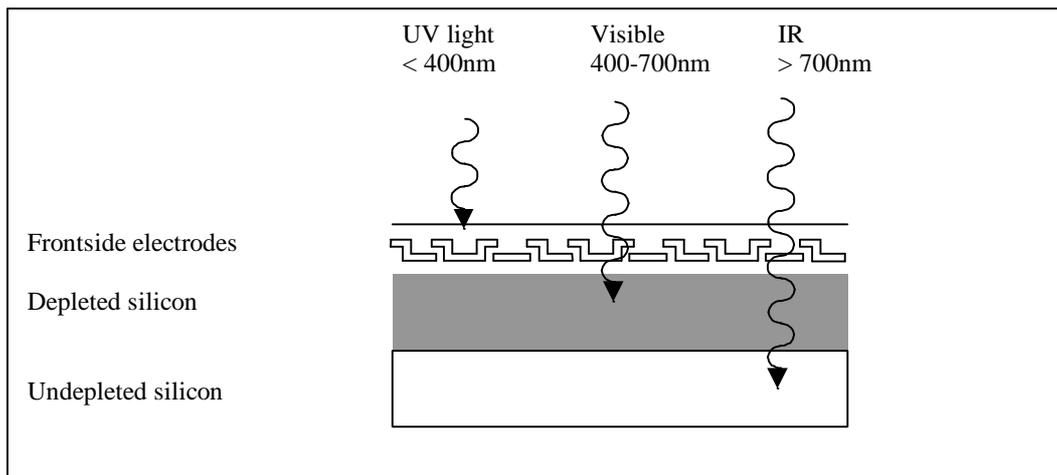


Figure 1a. Photon absorption in frontside illuminated CCD; an undepleted region is also shown.

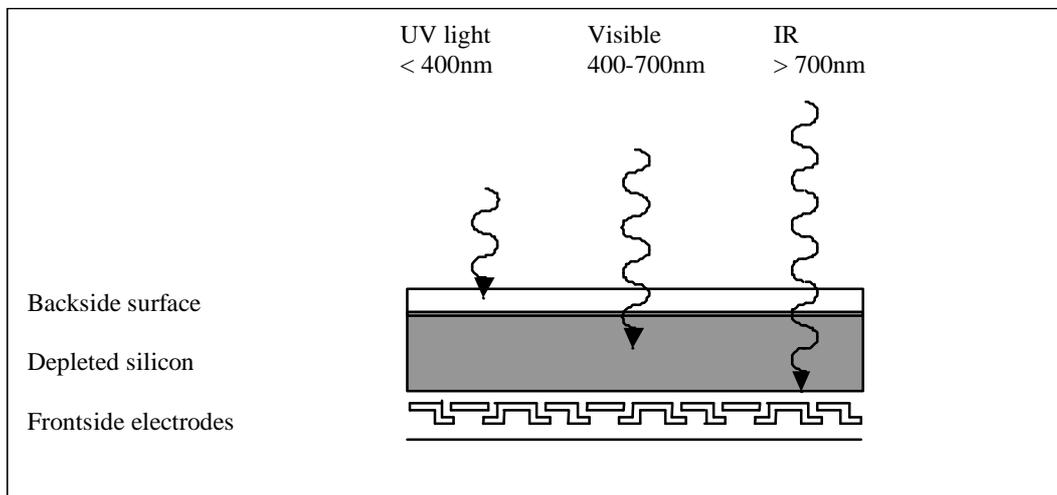


Figure 1b. Photon absorption in backside illuminated CCD

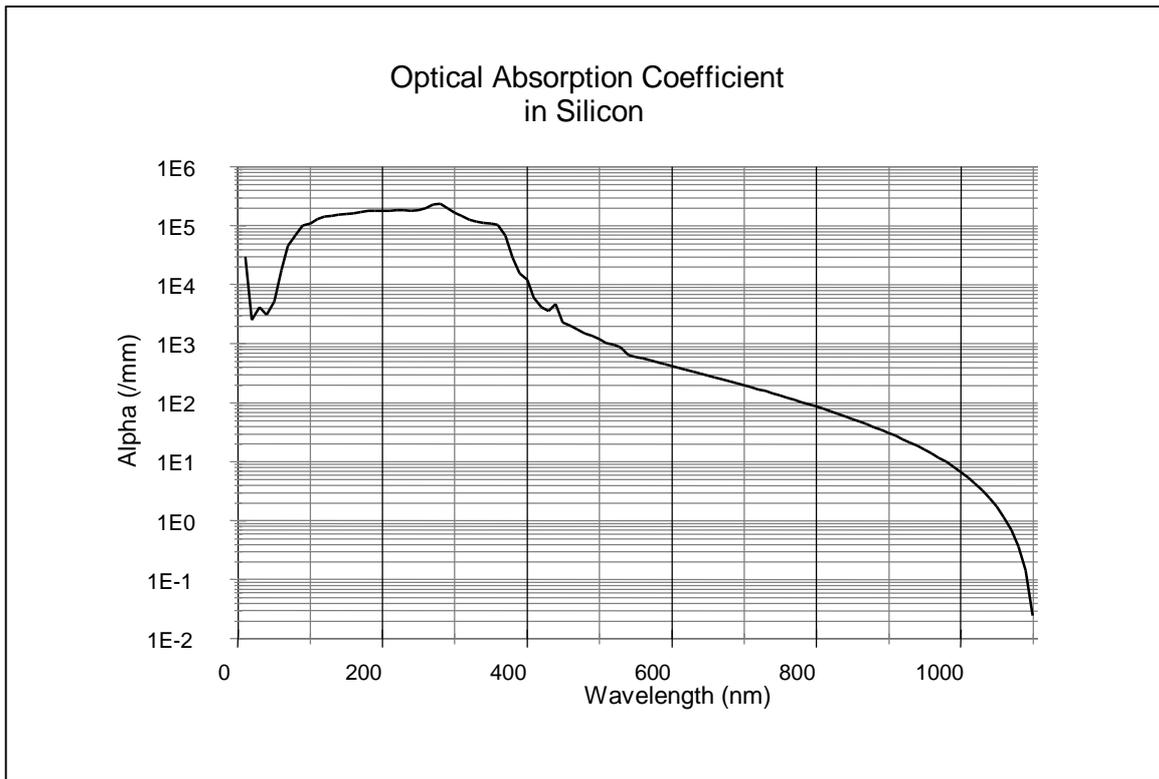


Figure 2. Silicon absorption coefficient

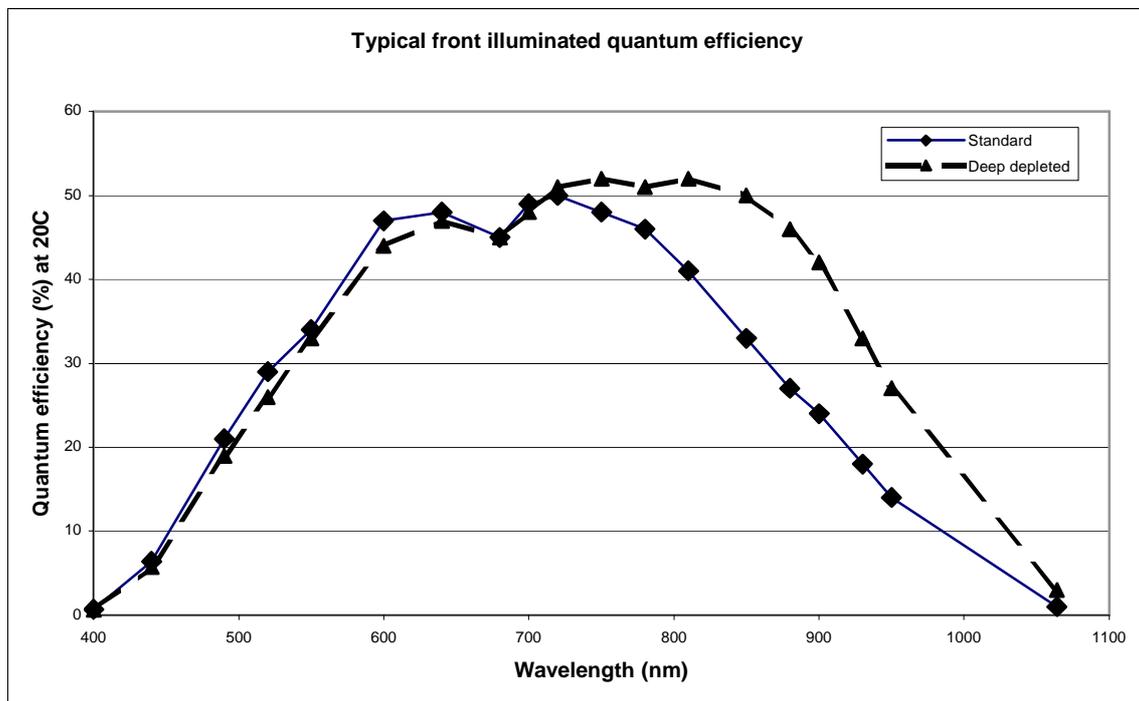


Figure 3. Frontside illuminated CCD- comparison of standard and deep-depletion silicon response.

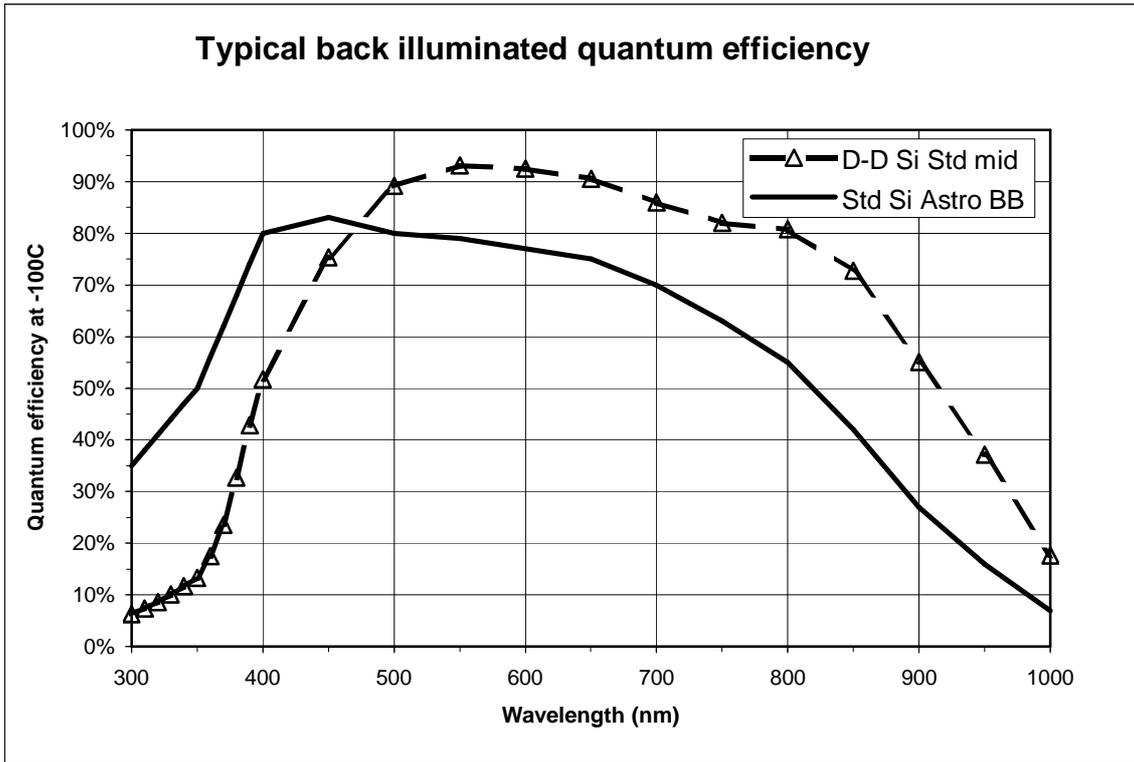


Figure 4. Backside illuminated CCD- comparison of standard and deep depletion silicon (note that different AR coatings have been applied in the two cases).

Whilst e2v technologies has taken care to ensure the accuracy of the information contained herein it accepts no responsibility for the consequences of any use thereof and also reserves the right to change the specification of goods without notice. e2v technologies accepts no liability beyond that set out in its standard conditions of sale in respect of infringement of third party patents arising from the use of tubes or other devices in accordance with information contained herein.