Automated optimisation of FT-CCD Image Pixels

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The performance of FT-CCD pixels can only be adequately modelled by means of 3-D electrostatic simulations [1,2]. With the Philips simulator PADDY one can perform the simulation of a CCD pixel with 100.000 mesh points and extract the required typical CCD performance parameters in $\approx$ 100 s CPU time at an HP9869 computer. This opens the way to an automated investigation of the parameter space and thus an optimisation of design parameters of the CCD-pixels. This possibility is attractive and has been tested in the development of new pixel geometries for which no good initial guesses for the doping distribution are available.
The simulated 4-phase (F1-F4) CCD pixel is shown in Fig. 1: on an n-type substrate, a deep profiled p-well is obtained after a high-temperature drive-in of a striped p-implant.

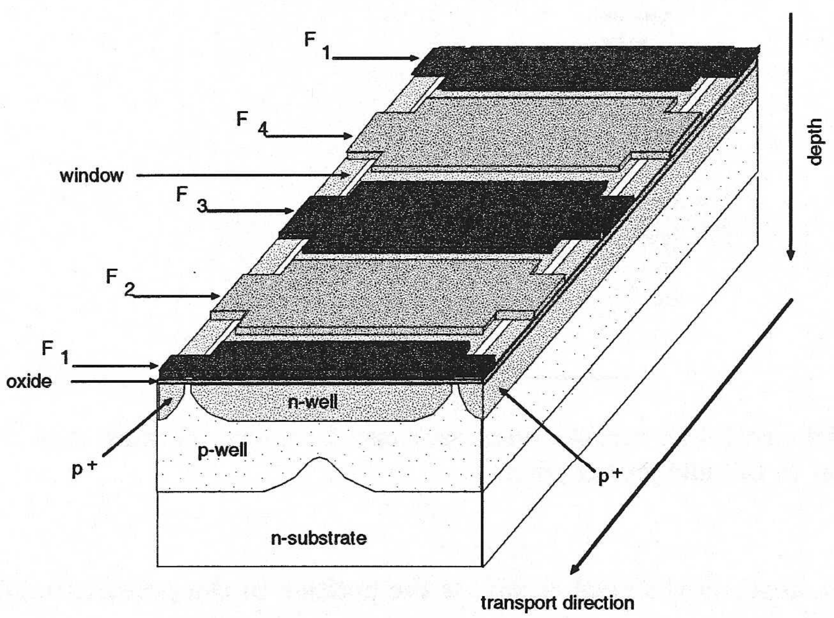

Figure 1: geometry of pixel

Next, the CCD channel is obtained by an n-implant followed by a new drive-in step. Then the p^+ channel stops are implanted. The next steps in the processing define the gate electrodes. For the simulations, two neighboring pixels were considered, one empty and one with a free electron package in the CCD well. The following parameters were varied:

- the top doping concentration, p_top, of the profiled p-well,
- the depth of the profiled p-well, p_char, describing the profile as a Gaussian distribution with a maximum at the Si-SiO_2 interface,
- the top doping of the n-implant n_top,
- the width of the implant mask for the profiled p-well, p_width,
- the voltage applied to the substrate, vsub.

The filling of the package with electrons was controlled by adaptation of the quasi Fermi level of the package up to the point where the vertical antiblooming barrier, ΔVAB (Fig. 2), is about 0.4 Volt. This height of the antiblooming barrier allows the overflow current to flow to the substrate at about 1000 times overexposure [2]. The magnitude of the overflow current is heavily dependent on the height of the antiblooming barrier [3]; the number of electrons is much less sensitive to this height, allowing using this number at a 0.4 Volt barrier as indicator for the maximum charge content of a pixel. From the resulting potential profile, with appropriate voltages applied to the p^+ channel stops and the integrating and blocking gate electrodes the following quantities are determined as shown in Fig. 2.

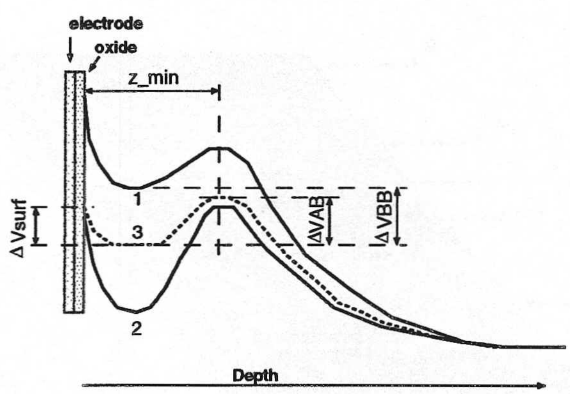

Figure 2: Potential profiles in vertical cross sections; 1: under blocking gate, 2: in empty integrating pixel, 3: in full integrating pixel

- the collection depth of the pixel, z_min, is the position of the potential minimum below the integrating gates,
- the collection volume, coll_vol, is the total volume in a pixel from the surface to the potential minimum, where generated electrons are captured in the potential well,
- the number of electrons in the full pixel in the collection volume, num_el,
- the lateral barrier ΔVBB between a full package and an empty pixel,
- the anti-blooming barrier, ΔVAB, between a full well and the substrate, which has to be about 0.4 Volt for proper anti-blooming,
- the interface barrier, ΔVsurf, between a full package and the Si-SiO_2 interface.

A figure of merit can be determined as a function of maximum charge capacity, collection depth, collection volume and lateral and vertical barriers. For each set of the five input parameters, about 6 simulations are performed with different quasi Fermi levels for the electrons of the full pixel until the anti-blooming criteria are satisfied. For each of the 5 input parameters 3-5 values were chosen over the feasible range. The matrix consisting of all the possible combinations results in more than 1500 simulations which were realised using the idle computer capacity over night. With the specified parameters as input and the extracted quantities as given above as output a Response Surface Method like relation has been constructed with a Multivariate Adaptive Regression Splines method [4]. With the resulting simple model the output variables can be predicted also at points between the available input data and a quick interactive scan and visualization can be done. Moreover different functions of merit can be evaluated and the parameter settings for the optimum value can be extracted without extra time consuming simulations. In Fig. 3 the visualisation of some parameters at a 2D cross section in the 5D parameter space with slider bars etc. for the input variables is shown.

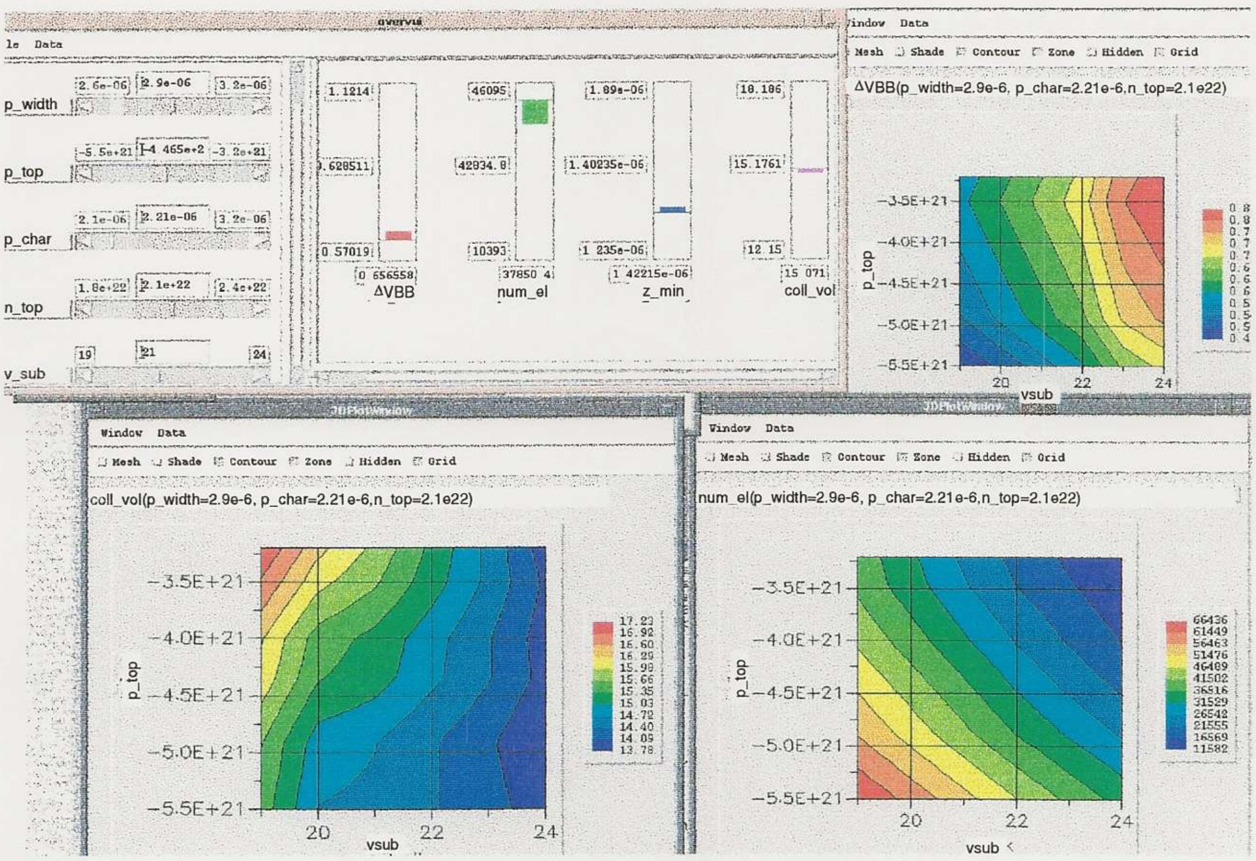

Figure 3: Representation of results in a 2D cross section of the 5D parameter space: ΔVBB, coll_vol and num_el as a function of p_top and vsub

From the results an optimum parameter set can be found and moreover an impression of the sensitivity of parameter variations can be derived. The approach developed here can also be used to perform a sensitivity analysis for existing CCD pixels; in this situation 2 or 3 values for each parameter are sufficient and thus a larger set of parameters can be used (e.g. also gate voltages).

References:

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