R37:Technology to Eliminate Yield-Limiting Elements in CCD Imagers

Herman Peek, Daniël Verbugt, Holger Stoldt, Ann De Veirman

Philips Semiconductors
Image Sensors
Prof. Holstlaan 4, 5656 AA Eindhoven, The Netherlands
Tel: +31-40-2742938, Fax: +31-40-2744090, E-mail: peek@natlab.research.philips.com

Abstract

Two yield-limiting problems in an FT-CCD technology have been discovered under normal light exposure.
- The first problem appears as small horizontal black stripes and is caused by isolating SiP precipitation on grain boundaries in intra poly-Si gate connections;
- The second case is black point defects that occur in a regular diagonal pattern. These defects are caused by minor pixel non-uniformities which are created on purpose to assure reliable contacts from the shunt wiring to the transfer gates.
The solutions to these problems meant decreasing the grain size of the poly-Si layers and creating elegant "click-button" contacts.

Introduction

Metal shunt wiring in megapixel image sensors for fast and optimal charge transfer is widely used in both Frame Transfer and Interline Transfer imagers. Both Aluminum and Tungsten shunt wiring have been used. A very successful shunt wiring technology, described in [1,2], employs groove filled tungsten. A buried poly-Si etch stop layer is used to define the bottom of the grooves. A standard lay-out of a 4-phase FT pixel (with a 2 layer poly-Si gate technology) is shown in fig.1a. The grooves filled with tungsten are not indicated in fig. 1. The (blue) sensitivity is mainly determined by the open areas in the poly-Si gate structure.
In FT-imagers for broadcast applications [3] the image format can be switched between 4:3 and 16:9 by changing the clocking scheme from 4-phase to 3-phase. To realise this a 12-phase gate-connection scheme is necessary (fig. 2). All gates should be optically identical to prevent pixel non-uniformity in either mode. The pixel layout is shown in fig. 1b. One CCD gate is half made from a relatively thick (0.4 μm) but narrow low-ohmic poly-Si part. It prevents deforming the shape of the clocks due to large RC values at the middle point between connections to the shunt wiring. The second half of the gate is made from a large high-ohmic membrane (0.05 μm) poly-Si part that increases the sensor's sensitivity.
The functional yield of these imagers was strongly limited by two special problems:
Horizontal black stripes and black point defects in a regular diagonal pattern.

Horizontal black stripes

In the 12-phase repetition structure shunt wiring straps are present in every other column, so one gate is strapped every 24 columns. From fig. 1b and 2 it is clear that between two connections to the straps two half-gate series are present. They run in parallel. One half-gate is made of relatively low-ohmic poly-Si (sheet resistance <50 Ω/□) and the other one is high ohmic (sheet resistance >1.8 kΩ/□). Although one part of a gate has a high resistance we can still realise perfect charge transfer if the other part of the gate, made in relatively thick poly-Si, is highly doped.
However, under nominal uniform exposure, the image suffered from horizontal black stripes with a length of at most 24 columns (fig. 3). The appearance of this phenomenon was random.
If at least two breaks exist in the relatively thick part of one gate between two connections to the straps, we can explain this phenomenon. Such breaks could leave parts of the gates floating; poor integration and bad transport can be expected.
Because no optically visible breaks could be found after a thorough inspection, an intensive study of the poly-Si structure was started [4].
For this purpose samples with meander shaped test structures in 0.4 μm poly-Si were made. The poly-Si films were doped in a $POCl_3$ furnace at 950°C for 15 minutes (standard conditions) and 30 minutes. Fig. 4 shows plan-view TEM images of both poly-Si films, clearly showing much larger grains for the 30 minutes sample. Also very clear is the presence of a second phase along the grain boundaries (indicated by white arrows) with a typical size of several μm's. After careful inspection of the 15 minutes sample these precipitates were found as well. The density of precipitates is estimated to be about $1x10^7$ per cm^2 and their typical size is 80 by 500 nm. As visible in fig. 4 the typical size of the precipitates is much larger for the 30 minutes sample. Hence further identification of these precipitates was performed with the 30 minutes sample.
Because the precipitates were so large selected area electron diffraction (SAED) could be done. From these analyses it could be concluded that the SiP precipitates have a monoclinic SiP structure [4,5].
When poly-Si films are etched in lines of dimensions in the order of 0.5 to 1 μm the role of SiP has to be further investigated. For this reason VC-SEM (Voltage Contrast-SEM) was performed on the meander shaped test pattern.

In fig. 5 a series of VC-SEM images is shown. The poly-Si lines are 3.5 μm wide and were doped for 30 minutes. Fig. 5a shows the whole meander with the metal contacts on both sides. On the bottom contact +2.5 V was applied. The positive bias at the bottom part of the meander gave rise to a dark secondary-electron image [4]. In the centre of the image a discrete location is present with reversed contrast to the poly-Si. When the positive bias is applied at the metal contact at the other side the secondary contrast is reversed.
Fig. 5b and 5c show SEM pictures of the same specimen at this particular location. Fig. 6a shows not only a TEM picture of a comparable situation but also the X-ray mappings, obtained by using the SiK and PK peaks (fig. 6b,6c). From these energy dispersive X-ray (EDX) and SAED analyses a concentration of 50/50 Si/P was derived.
From the combination of VC-SEM and TEM it can be concluded that the monoclinic phase is a high-ohmic material. Electrical problems can occur as soon as grain sizes, and consequently the SiP precipitates have dimensions comparable with the line width of poly-Si structures. And this is of course the case at the intra poly-Si gate connections (± 0.6 μm). The solution is to prevent the grains from becoming too large. This can be done by decreasing the $POCl_3$ deposition temperature to 900°C. The increased sheet resistance from 43 to 50 Ω/□ did not influence the performance of the imagers.

Diagonal black point defects

Under nominal uniform light it was also possible to observe black point defects of low intensity situated in a regular diagonal pattern over the whole screen (fig. 7). It turned out that the black point defects coincided with the position of the contacts of the shunt wiring to the gates. To assure reliable contacts in both thick and membrane poly-Si layers and no gate-dielectric defects, small square broadenings were made at these contact area's (fig. 1b). The third poly-Si layer is used as an etch stop during groove etching for the sunken tungsten shunt wiring technology [1,2], and is also responsible for reliable contacts between tungsten and the gates. To maximise the sensitivity one must use a minimal width for this structure. Due to misalignment the broadenings in the gate patterns are sometimes partly visible within the open windows, causing minor pixel non-uniformity. This results in fractionally less sensitivity for that pixel. The misalignment occurs over areas in the image section and appears as diagonally organised black point defects.
To solve this problem a new very reliable shunt wiring contact technology, called the "click-button technology", has been introduced. The broadenings have disappeared, replaced by the straight lines of the intra poly-Si gate connections (fig. 1c). The dimensions of these narrow gate connections are minimal, and actually no reliable contact hole to poly-Si 3 fits on top. Fig. 8 shows a cross-section perpendicular to the two narrow intra-gate connection and along the p+ channelstop. In fig. 8a the situation after oxidation of the membrane poly-Si part is shown. 40 nm silicon nitride is grown afterwards. By a lithographical CS mask step and anisotropic nitride etching an oversized contact hole is made in the last deposited nitride layer, leaving only some spacers alongside silicon oxide steps and some thinned nitride regions outside the two poly-Si intra gate connections (fig. 8b). The widths of these regions and the contact holes are determined by the minimum dimensions of lithography, but fit easily underneath the poly-Si 3 lines which is deposited later.
Now a very uncritical but very important mask-less wet oxide etching can be applied (fig. 8c). It is the underetching and the perfect filling of the cavities underneath the nitride with poly-Si 3 that assures a very tight and reliable connection between the three poly-Si structures (fig. 8d). This connection looks like a click-button and can best be seen in a cross-section in the other direction. Fig. 9 shows a TEM cross-section of fig. 8d.
It should be emphasized that this elegant technological solution is only possible by using silicon oxide and nitride as gate dielectrics.

Conclusions

Two yield-limiting elements in CCD technology have been investigated and eliminated:

- Small horizontal black stripes were caused by isolating SiP precipitates in poly-Si lines with line width dimensions of the same order as the grain size. Simply decreasing the grain size by lowering the $POCl_3$ deposition temperature to 900°C is not a spectacular measure but does solve the problem, and such a simple solution was only possible after in-depth research.
- The black point defects caused by minor pixel non-uniformities were eliminated by introducing the "click-button" contact technology, connecting three poly-Si layers to each other without deformation of the regular structure of each pixel.

References:
[1] H.L.Peek et al., Proc. IEDM'93 Conf. p.567-570
[2] H.L.Peek et al., Proc. IEDM'96 Conf. p.907-910
[3] H.Stoldt et al., Proc. IEDM'96 Conf. p.899-902
[4] A. De Veirman et al, to be published
[5] A.Bourret et al., Ultramicroscopy , Vol.14, no 97, 1984

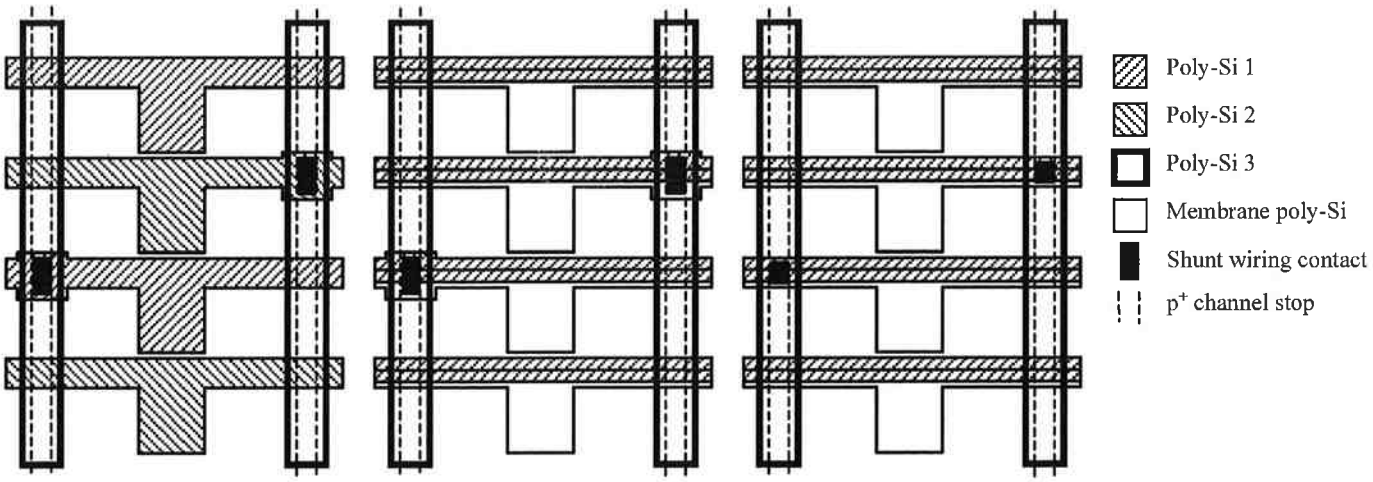

Fig. 1a. Conventional pixel layout.

Fig. 1b. Pixel layout with "identical" gates.

Fig. 1c. Pixel layout with fully identical gates.

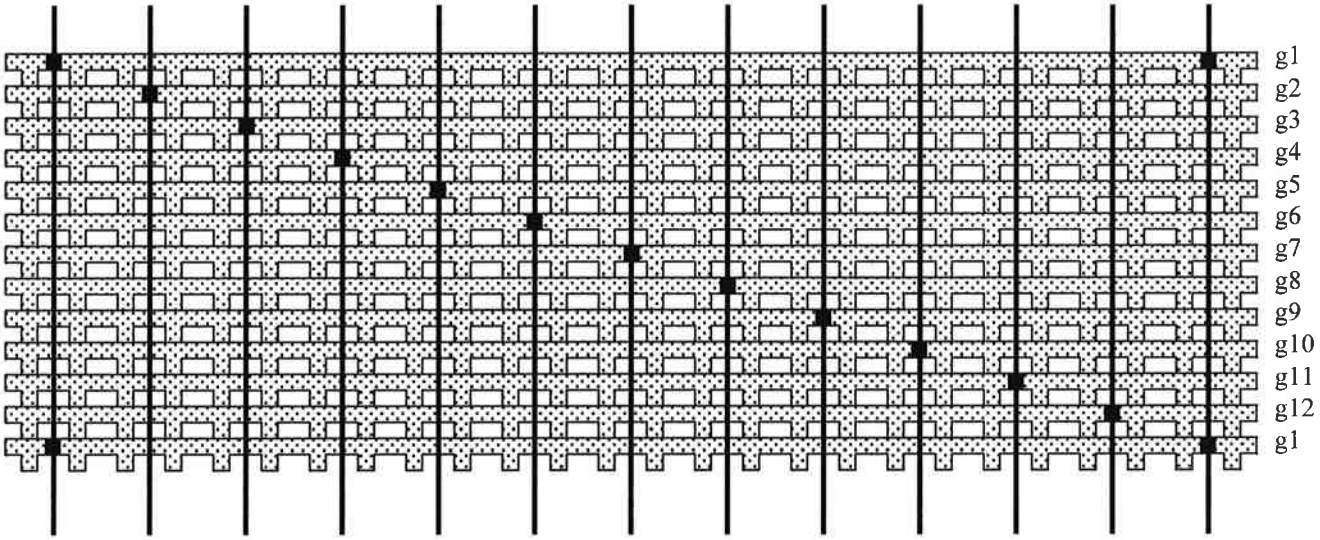

Fig. 2. 12-phase system for 4-phase and 3-phase switching clocking schemes.

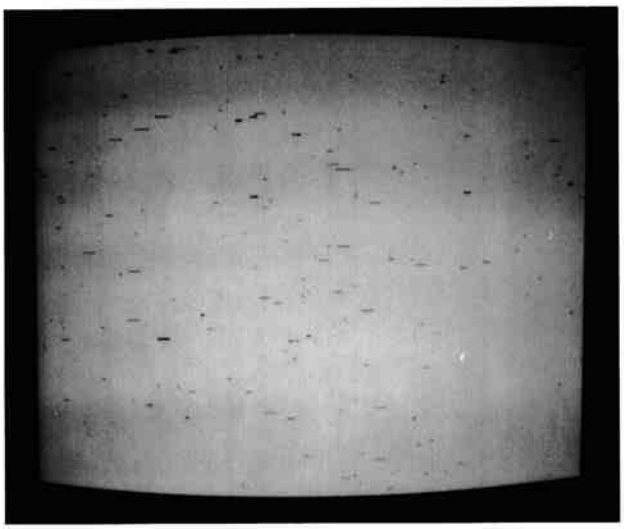

Fig. 3. Photograph from video monitor showing small horizontal black stripes.

Fig. 4. Plan-view TEM images of $POCl_3$-doped poly-Si at 950 °C for 15 and 30 minutes. SiP precipitates are indicated by white arrows.

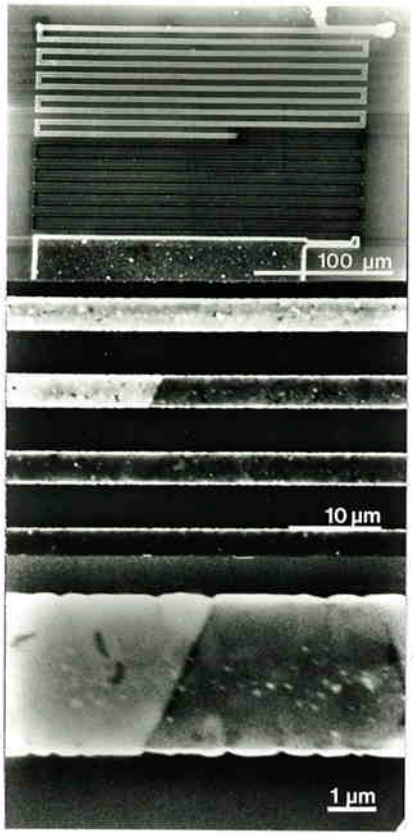

Fig. 5 Voltage-contrast SEM images of the same area at different magnification. Applied voltage at bottom contact (a) + 2.5 V (b+c) +1.0 V

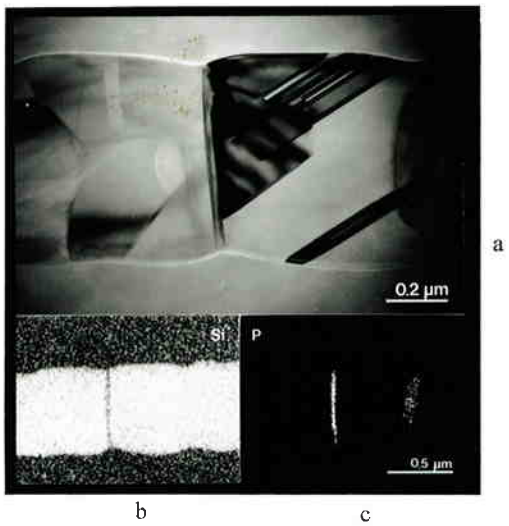

Fig. 6 TEM of a SiP precipitate with X-ray mappings of Si and P

Fig. 9 TEM cross-section of situation in fig. 8d

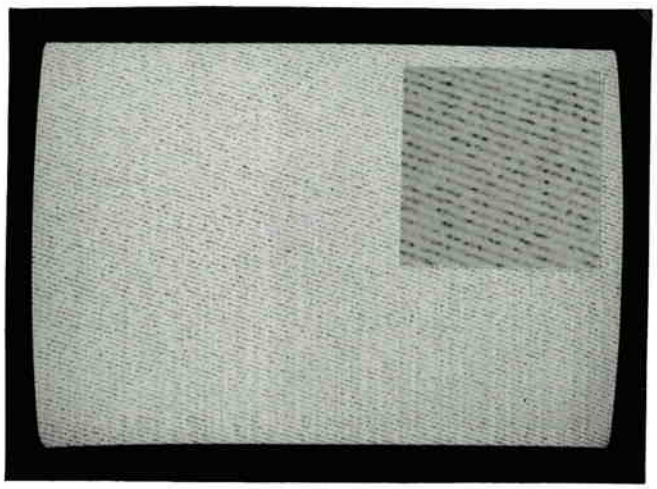

Fig. 7 Photograph from video monitor showing diagonally organised black point defects

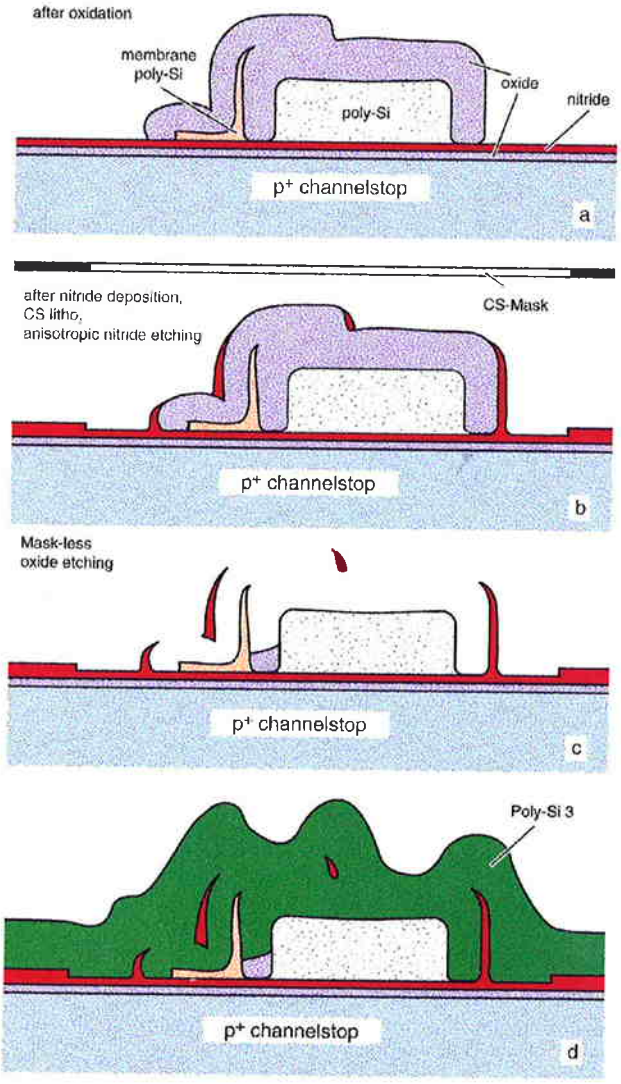

Fig. 8 Cross-sectional view of the "click-button" technology