New Sensor Technology

Case Study: Commercialization, R&D to Manufacturing

Mountain View Energy

Introduction

In the mid-1990s, several companies were vying to become the dominant CMOS image sensor manufacturer, and compete with CCD imagers. One large electronics manufacturer was one of the competitors, and developed what was at the time, a state-of-the-art product. One major limiter was the design rule conflict of minimizing pixel size (for cost, size, and resolution), and maximizing both photodiode (for maximum sensitivity), and pixel circuitry (for minimum noise and power consumption). They thought that one strategy around this was to remove the photodiode from the substrate and place it on top of the array.

We were asked to develop an α-Si:H photodiode technology, including materials development, device architecture, and performance control structures; as an alternative to crystalline CMOS circuitry. We developed the program from research concept, and took it through to manufacturing demonstration.

Challenge

The primary product constraint was since the photodiode was to be created after the forming gas anneal, the maximum process temperature had to be below 400˚C. There was only one known deposited semiconductor known at the time that could de processed below that limit, α-Si:H. The material primary constraint was a tradeoff between material quality and deposition rate. It also has a performance constraint in which photon absorption can create additional metastable trap states (a.k.a. Staebler-Wronski Effect). Lastly since the concept required additional processing (i.e. cost) the device architecture needed to minimize that cost to speed the crossover point to profitability.

Action

The state-of-the-art α-Si:H process known by the field was slow low, that the incremental capital requirements would have required a 33% investment with respect to the current line, so the first task was to create a process that would

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improve upon that. By utilizing modifying existing equipment, we were able to provide the client with a process that had a 10x rate over current process along with a defect density that matched state-of-the-art material, (reduced incremental cost to 3%.) After creating a commercially viable process and high-performance material, we set about creating the diode and device architecture. The key innovations here were creating highly doped yet thin contact layers to maximize the quantum efficiency of the photodiode. The contact layers produced a device with 10^{-11} A/cm^2 leakage (10x lower than previously reported devices, with 10-20nm contact layers, yielding a blue QE of 45%, peaking in the green at 80%, (comparable c-Si devices had 30% QE).

To minimize incremental cost, not only was a high deposition rate required, but minimizing the number of steps for for the array was critical. The client proposed a 7-mask process, which would have added 50% to device processing. By creating a guard ring around the array, we would negligibly increase area, but reduced the number of steps so the cost increase was only 30%.

The metastable trap state issue, required innovative thinking at the system level. Several distinct artifacts were created during use conditions, but since they were a fundamental materials phenomenon, we understood that overcoming these artifacts required system-level solutions. We framed the discussion on how we could change design and operation of the product with a constraint of not increasing product cost. We identified design and operation solutions including creating barriers using by modifying the layout, adjusting the pixel bias waveform taking advantage of inherent device latency, and utilizing existing memory in the customer's product.

Results

By leveraging the capabilities of a modern integrated circuit fabrication facility, we found solutions to these materials issues quickly, and developed a working diode array prototype within three months. By putting the material and device architecture solutions in place, we were able to demonstrate a working cell in 3 months, and a working image sensor in 6 months. Implementing the system-level solutions took another 12 months. There was tremendous interest from the client's divisions, so we transferred it from their R&D laboratory to their production facility and started scaling within 12 months.

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