TRL Advancement and Qualification of Si Detector Arrays

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Program: Strategic Initiative

Project Objective:

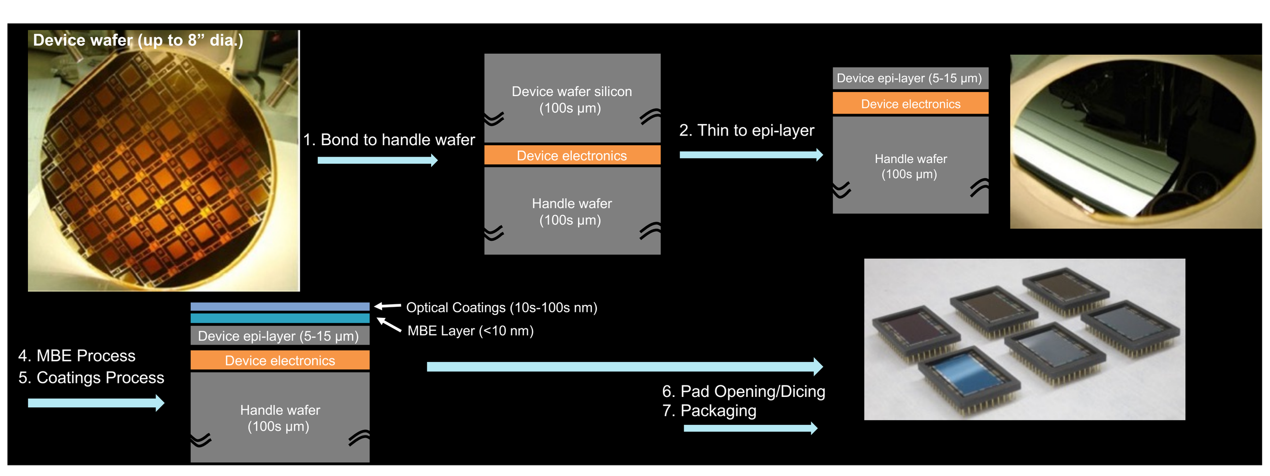
JPL has developed and established a strong ultraviolet detector capability and other UV instrument technologies such as filters and cotatings. To a large part, the high performance achieved is enabled by microdevices laboratory (MDL) technologies of interface and surface engineering using molecular beam epitaxy (MBE) and atomic layer deposition (ALD). Delta doping, or more generally 2D doping, is a back-illumination technique developed at JPL in collaboration with leading CCD and CMOS manufacturers, including Teledyne-e2v (e2v). Delta-doped devices exhibit 100% internal QE and their external QE can be further enhanced and tailored with custom coatings [Nikzad 2017, Nikzad 2016, Hoenk 2014]. Delta doping has been demonstrated on numerous CCD and CMOS arrays, which have been independently characterized to show exceptional stability of response in the entire UV regime including the far UV (FUV) range. In partnership with e2v, our team has produced UV-enhanced electron multiplying CCDs (EMCCDs) for high efficiency UV photon counting detectors that successfully flew on September 22, 2018 on the FIREBall-2 stratospheric balloon experiment. The partnership will also deliver the FUV and near UV (NUV) CCDs to the SPARCS CubeSat mission. Delta-doped and custom-coated e2v EMCCDs and e2v conventional CCDs are baselined for a number of Explorer mission concepts. We have an opportunity to work with e2v on a scale that could result in producing devices with high statistics for testing and evaluation in space environment. This year, we initiated the first step of detector advancement by processing a batch of wafers through the first step of processing, i.e., direct wafer bonding of blank silicon wafers to the device wafers so that they act as mechanical support after the device wafer is thinned down to less than 20 microns.

FY19 Results:

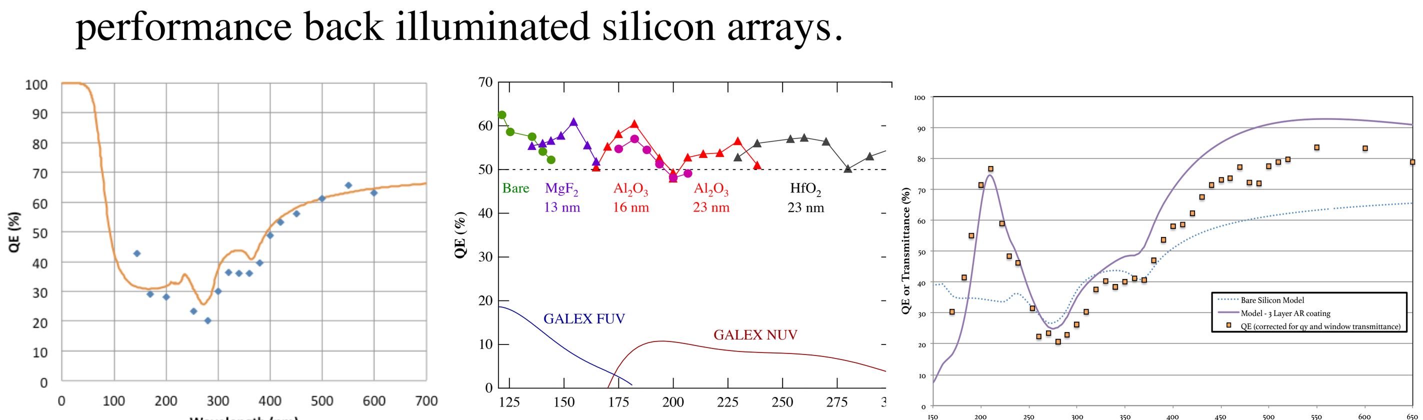
We have been working with Teledyne-e2v—a leading manufacturer and deliverer of scientific CCDs for space missions—through R&D tasks as well as detector deliveries for suborbital missions. We have applied JPL's back illumination processes (Fig1) including the 2D doping (delta doping and superlattice doping using MBE) and advanced coatings and detector-integrated filters (using ALD) to create detectors with unprecedented QE and response stability (Fig 2). These have led to success in R&D projects as well as suborbital flights such as FIREBall balloon experiment (first flight Sept 2018, two additional proposed flights in 2020 and 2021). The successes have further led to more interest from the UV science community, e.g., SHILEDS, a heliophysics sounding rocket (first flight planned for April 2020) and CubeSats. We are in process of building a two-channel UV camera for the SPARCS CubeSat (planned launch in 2021). Currently five Explorer concepts (2019 SMEX AO) have baselined 2D-doped detectors from JPL. One SMEX concepts has baselined a UV CMOS with a UV CCD as backup. All the rest SMEX proposals are asking for various forms of photon counting or conventional CCDs with high UV response using JPL technologies. Through discussion over the past several years and most recently in the past few months, e2v has come to the table for a collaborative effort using cost sharing (each party pays for their part of the effort) to get more statistics on the end-to-end fabrication and back illumination processes in order to certify the process and also as a result advance the TRL. Figure 1 shows the overview of JPL general process flow and performance. In FY2019, we initiated the first step of this process flow (figure 1).

Benefits to NASA and JPL (or significance of results):

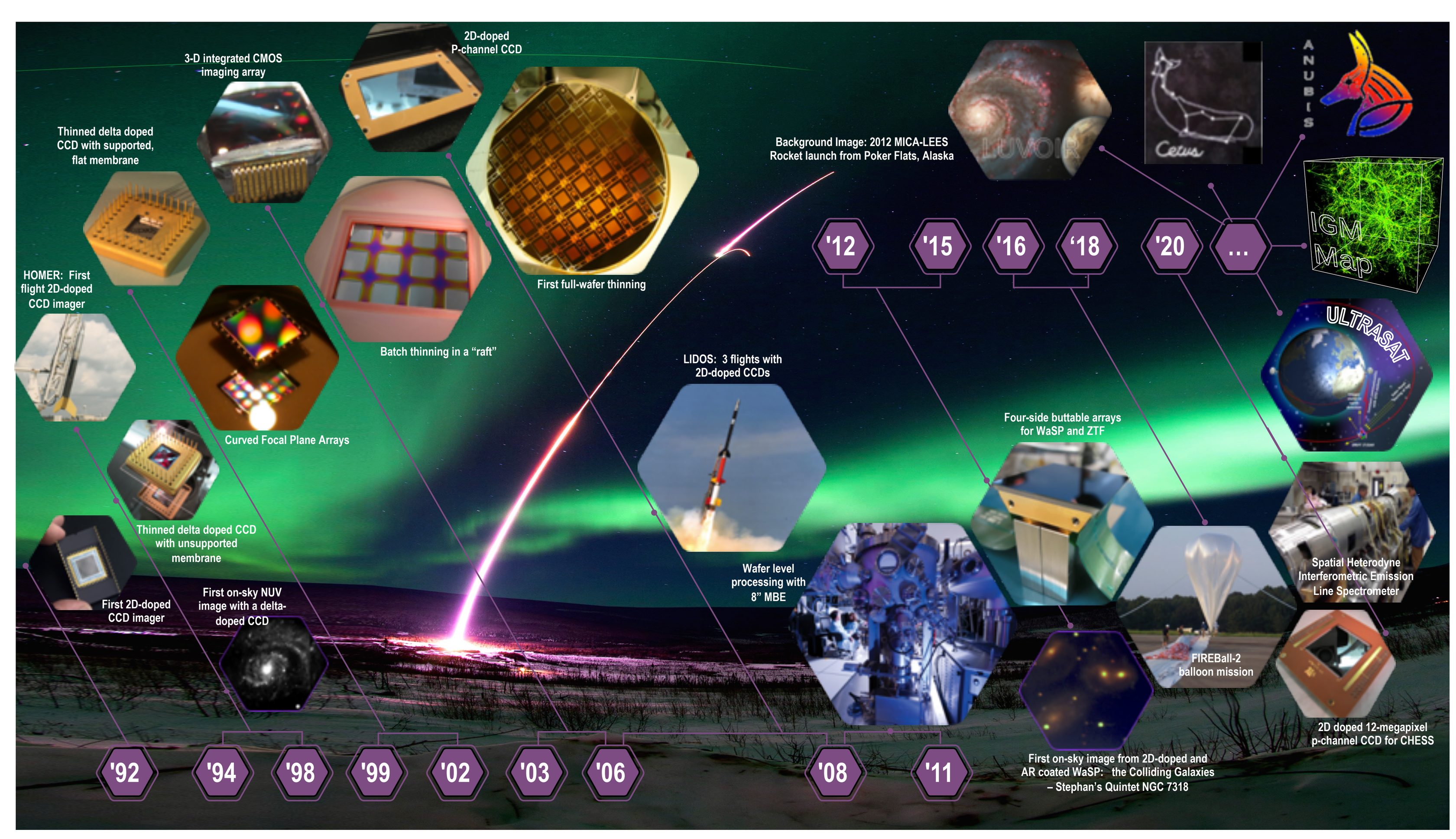
This effort addresses the need for advancing the maturity of high performance detector technology for near and long-term ultraviolet (UV) and UV-Optical missions. There are a record number of exciting Explorer mission concepts in various stages of formulation, planning, or submissions with their science objectives ranging from detection of UV counterpart to gravitational waves (GW), to time-domain UV astronomy, massive star life cycle, exo-solar planetary atmospheric studies in the context of their stellar UV environment, intergalactic medium and circumgalactic medium emission studies for understanding the baryonic life cycle, and more. Ultraviolet spectral range in many respects represents the "undiscovered country" element in Explorer mission with its abundance of diagnostic spectral lines and its untapped time domain astronomy. With GALEX mission completed and Hubble Space Telescope likely to end its mission soon, the need for ultraviolet mission(s) is urgent as well as important. Additionally, NASA-funded flagship mission studies, HabEx and LUVOIR have multiple instruments requiring high performance UV and UV-optical photon counting or other scientific UV detectors. JPL's 2D detector technology (encompassing delta doping and more recently superlattice doping) provide 100% internal quantum efficiency (QE) while their associated coatings using atomic layer deposition (ALD) provide tailorable response in ultraviolet and ultraviolet-optical spectral range. 2D-doped and custom coated photon counting and scientific silicon arrays are enabling for the missions mentioned above but they need further testing to mature to TRL6 so that when proposed as baseline detectors in NASA proposals, the technologies are not considered a risk and won't pose a threat to an otherwise winning proposed mission concept. With this effort, we aim to advance JPL's back illuminated silicon detector technology and post fabrication end to end processing so that they can be leveraged as mission enabling and win themes in NASA proposals. In addition to astrophysics proposals, these detectors have applications in planetary missions such as New Frontiers and Discoveries.



Process flow of JPL's post fabrication processes including direct wafers bonding, thinning, 2D doping and advanced coatings which lead to high performance back illuminated silicon arrays.



100% internal QE that is resulted from bare delta doping and no AR coatings (left), example of simple single-layer AR coatings resulting in high QE in the UV (middle), example of multilayer coating for optimization of QE at 205 nm.



Arc of the JPL UV and back illuminated high performance silicon detector arrays with highlights and milestones. Under the current effort, these high performance detectors will be going through qualification and TRL advancement in partnership with Teledyne-e2v.

Publications:

None.

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