# PtSi IR ARRAY IN MOSAIC CONFIGURATION

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ABSTRACT: The rapid progress in the focal plane technology enables us to use large format infrared sensors, such as 256 x 256 InSb/HgCdTe and 1040 x 1040 PtSi arrays. Infrared two-dimensional sensors make possible not only the imaging observations but a deep detection limit. The development of a large format infrared array is one of the most important breakthroughs in observational astronomy.

We propose to build a mosaic infrared camera for the SUBARU 8-m telescope. The SUBARU telescope is designed to reach a diffraction limited image at infrared wavelengths with a wide field of view (six arcsec at the Cassegrain focus). The camera is designed to cover the entire field of view with PtSi infrared sensors and to employ a weighted shift-and-add operation and a real-time image processing. The efficiency of the mosaic infrared camera and power of the 8-m telescope have a strong potential to meet challenging problems. Most of the regions of the near infrared sky are not covered with enough sensitivity. It is essential to conduct infrared deep and wide surveys.

## 1. INTRODUCTION

It was only ten years ago that the first infrared camera was applied for astronomical observations (Forest et al. 1985). It was a very drastic change in infrared astronomy since the infrared array was the first imaging tool in the infrared region. The infrared array was a very large quantum jump in observational astronomy, similar to that of the photographic plate. This decade has been the epoch in which a number of infrared cameras have been developed for astronomical uses and the format size of infrared array has been getting larger and larger. We have been developing PtSi infrared arrays under collaboration with the semiconductor research and development laboratory, Mitsubishi Electric Co. in Japan (Ueno et al. 1992), and we are building a prototype model of the mosaic infrared camera.

## 2. THE SUBARU TELESCOPE

The SUBARU Japanese National Large Telescope project is being promoted by the National Astronomical Observatory, Japan. The SUBARU project aims to construct an 8-m



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infrared/optical telescope with excellent image quality atop Mauna Kea in Hawaii. The SUBARU telescope employs an active support system of the primary mirror to maintain a precise optical surface and to reduce gravitational distortion, a dome flushing system to reduce atmospheric turbulence inside the dome and precise driving of the telescope with direct driving motors. Using these new technologies, the SUBARU telescope is designed to realize 0.2-0.3 arcsec near infrared seeing and diffraction-limited imaging with an adaptive optics/speckle interferometer. The field of view of the primary focus and the Cassegrain focus of the SUBARU telescope are 30 arcmin and six arcmin respectively. The prime focus of the SUBARU telescope contains optical and infrared corrector lenses.

## 3. THE PtSi ARRAYS

The PtSi infrared array detectors have been developed under collaboration with Mitsubishi Electric Co. (Kimata et al. 1987, Ueno et al. 1992). The current performance and specifications are tabulated in the following table.

TABLE 1

Parameters for Infrared Arrays

| 512 x 512 PtSi Infrared CSD | |
|---|---|
| Number of pixels | 512 x 512 |
| Pixel size | 20 micron x 26 micron |
| Read-out scheme | CSD (Charge Swept Device) |
| Quantum efficiency | 6% @ 2 micron |
| Filling factor | 71% |
| Read noise | $< 30\ e^-$ |
| Dark current | $< 3\ e^-$/sec @ 60 K |
| Full well capacity | $1.5 \times 10^6\ e^-$ |
| Uniformity | > 98% |
| Linearity (gain error) | < 1% |
| Defective pixels | < 0.01% |

1040 x 1040 PtSi Infrared CSD; developed in 1992. 1040 PtSi array has four output amplifiers and is manufactured by the Mitsubishi Electric Co.

| | |
|---|---|
| Number of pixels | 1040 x 1040 |
| Pixel size | 17 micron x 17 micron |
| Read-out scheme | CSD |
| Quantum efficiency | 6% @ 2 micron |
| Filling factor | 51% |
| Read noise | < 30 electrons |
| Dark current | < 1 electron/sec @60K |
| Full well capacity | $1.5 \times 10^6$ electrons |
| Uniformity | > 98% |
| Linearity (gain error) | < 1% |
| Defective pixels | < 0.01% |

The quantum efficiency of the PtSi array is about ten times lower than those of InSb and HgCdTe detectors. However the PtSi array has excellent uniformity, large format size, good stability, low read noise and an inexpensive cost. If the format size of the PtSi array is ten times larger than other's, the total efficiency for a wide field survey with the PtSi array must be quite comparable to that with other systems. These features of large format size, mass productivity and cheap costs suggest that we should build a mosaic infrared camera with PtSi arrays.

In 1991, we conducted a galactic center survey at H and K bands using the 512 x 512 PtSi camera and a Newtonian telescope with 25-cm aperture (Ueno et al. 1993, Fig. 1). In our survey, 12 square degrees of the galactic center region are covered with 35 frames of H and K band images. The stable response of flatfielding makes possible complete background limited observations and wide field mosaic image.

Recent progress in PtSi technology enables us to improve quantum efficiency. In addition to optimizations of the thickness of the PtSi layer and the cavity structure of the detector, the strong electric field of the contact layer of the PtSi is very effective in improving the quantum efficiency of PtSi arrays (Konuma et al. 1995). According to the new theory of the PtSi detector, the quantum efficiency is estimated to be more than 10% at two microns. The PtSi array uses CCD architecture for the readout system and the CCD has enough capability to get low readout noise under rapid operation. A low-noise HDTV CCD achieves 11 electron/pixel read noise for 70 Mpixel/sec readout speed, that is, two electron/pixel read noise for 512 x 512 pixel/100 m sec. The possible improvement in the quantum efficiency and readout noise shows the future capability of PtSi arrays. Improved PtSi arrays seem very suitable for low background uses such as spectroscopic applications and use as a speckle interferometer.

## 4. BEYOND THE CONVENTIONAL SPECKLE TECHNIQUE

Two approaches are considered to bring about high spatial resolution imaging, adaptive optics and use of an array as a speckle interferometer. Adaptive optics employs mechanical corrections using deformable mirrors to maintain the wave front, disturbed by atmospheric turbulence, while a speckle interferometer uses computational correction of disturbed images. The adaptive optics technique is a real-time operation and is very effective for spectroscopic applications as well as high spatial resolution imaging. The speckle interferometer is generally an off-line operation and is not suitable for spectroscopic observations and visible imaging because the read noise of the detector has a harmful effect on the sensitivity of the observations. Adaptive optics works only within an isoplaneatic angle since the mechanical compensator of the wave front is very difficult to expand beyond the isoplaneatic angle while the speckle interferometer can correct the entire field of view.

The conventional speckle interferometer has faced several barriers in applications for practical observations. The conventional technique uses independent observations of objects and calibration stars lying beyond the isoplaneatic angle using a self-calibration technique because the field of view of the camera system must be small at visible bands and also the isoplaneatic angle is typically ten arcsec in the visible region. In addition to this problem, the strong effect of the read noise reduces the visible sensitivity because a typical speckle life time is less than 10 m sec.

On the other hand, the isoplaneatic angle at two microns is typically one arcmin and its speckle life time is 100 m sec. We can get a sufficient number of guide stars in the near infrared region, that is, at least one guide star within an isoplaneatic angle. Freedman's parameter (D/R0) for the SUBARU telescope at two microns is five to ten. Under such a small Freedman's parameter condition, a tip-and-tilt operation as well as shift-and-add operation are usable for the high resolution imaging. The shift-and-add operation can align the peak of images and drive 5 to 10% flux into the diffraction angle.

The weighted shift-and-add operation seems a much more efficient technique under these conditions. The weighted shift-and-add operation aligns several peaks, for example first to seventh largest peaks, in a frame using the calibration stars in the same frame, then integrates the frames. More than 60% of the flux is estimated to fall within the diffraction angle after the weighted shift-and-add operations (Tsumuraya 1994). The weighted shift-and-add operation seems very suitable for a large aperture telescope with a good seeing condition.

## 5. DEVELOPMENT OF PtSi ARRAYS FOR THE SUBARU TELESCOPE

We have started developing new PtSi arrays under collaboration with Mitsubishi Electric Co. and Nikon K. K. in Japan. The goal of the new array is shown in the table below.

TABLE 2

Goal of New Array

| | |
|---|---|
| Number of pixels | 1024 x 1024 |
| Output amplifiers | 4 |
| Pixel size | TBD |
| Read-out scheme | CSD |
| Quantum efficiency | > 10 - 15% @ 2 micron |
| Filling factor | > 75% |
| Read noise | < 3 $e^-$/pixel for 3 M pixel/sec |
| Full well capacity | > 2 x $10^5$ $e^-$ |
| Device architecture | monolithic structure |

The new PtSi array is a very powerful detector for not only the mosaic applications but also for usual observations. We plan to develop a very cheap infrared camera system and make collaborations with small and middle size telescopes. In the infrared region, we have a chance to conduct good science even with a small telescope.

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DISCUSSION

FINGER: What is the limit of QE one can achieve with PtSi at the K-band and how can it be achieved?

UENO: According to the new theory in the Schottky-barrier mechanism, the QE of the SBD detector is determined not only by the work function of a metal material and thickness of the metal layer but also by the electric field behind the Schottky-barrier contact layer. A strong electric field improves the QE of SBD. This technique requires a small modification in the array structure.

IWERT: Large thinned CCDs are so far not produced by Japanese companies. Also the Subaru Project does not intend to enforce the contacts to Japanese industry to initiate these developments. However we see on your talk developments by Mitsubish and possibly Nikon for the development of large PtSi arrays. Where are the differences, and why does the Subaru Project not favor the development of CCDs from Japanese industry?

UENO: The Subaru Project still makes much effort to produce a large format CCD in Japan. However most of the CCDs are produced in commercial divisions. A typical commercial division of Japanese industry has no interest about scientific uses. The PtSi arrays are developed in R & D divisions and their engineers are strongly interested in the scientific instruments.

MOSELEY: Could you describe the optical system to be used with your mosaic array?

UENO: I plan to use 1:1 optics for the Cassegrain focus. (During lunch time discussion, Dr. Finger of ESO gave me a very helpful idea for the optics.) The Subaru telescope employs a primary focus corrector for 1 - 2.5 $\mu$m. We can put our mosaic camera simply at the prime focus if we would like to make wide field imagings. The pixel size of the PtSi array is designed to fit a diffraction limit scale at the F/13 Cassegrain focus and fit a seeing size at the F/2 prime focus.

JORDEN: For what reasons do you hope to achieve a readout noise of two to three $e^-$ at 3 megapixels/sec? Is this for a single, or multiple output device?

UENO: The PtSi array is designed to have four output amplifiers. The read noise of a CCD detector is determined by the node capacitance and gate noise density of the output source follower amplifier. The PtSi array will have 10 fF of node capacitance and very low noise MOS FET. These technologies are well realized in the HDTV CCDs in Japan.