BACK ILLUMINATED SYSTEM-ON-CHIP FOR NIGHT VISION

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http://www.e2v.com/
OUTLINES

- Back Illumination Technology Motivation
- The BII3 project at e2v
- Image Quality Metric
- Image Quality Comparison
- Conclusion
Back Illumination Technology

- Back Illumination technology was developed initially for the CCDs to improve Quantum Efficiency performance limited by front side absorption of poly-silicon gates (still used in CCD TDI for space application).

- In the late 2000's, majors or Consumer Imaging market have developed process for BI CMOS image sensor on an industrial scale. Motivation were to improve fill factor of pixel of pitch less than 2 µm.

- Conventional **Front-Illuminated** pixel comprises a microlens to guide light through CMOS stacks and has a limited “internal” numerical aperture. Crosstalk occurs for long wavelengths (Red, Near infrared).

- Numerical aperture of **Back-Illuminated** pixel is large and fill factor is 100%. Light absorption is maximized using antireflective coating. Crosstalk occurs for short wavelengths (Blue/Green).
BII3 PROJECT

- **I3**: project founded by the DGA, French Defense Agency
  - 1.3 Mpxels snapshot CMOS Image Sensor
  - Thick silicon: QE Broadband ~80%, NIR
  - Front-Illuminated Deep Depletion Photodiode: improved crosstalk
  - Low noise technology: 3.2 e- noise floor
  - Noise Equivalent Illuminance: 0.5 mlx @ 25 frames/sec (night light)

- **BII3**: Back Illumination I3 project, founded by e2v on the basis of FI I3
  - 1.3 Mpxels snapshot CMOS Image Sensor
  - Two versions, visible (thin silicon), NIR (thick silicon)
  - Back-Illuminated Deep Depletion Photodiode
  - Low noise technology: same basis of FI version
BII3 PROJECT

DESIGN TO TECHNOLOGY APPROACH:

1.3 Mpixels CIS based on EV76C560 System-On-Chip

5.3µm square pixels
Format 1/1.8”
60 frames/sec
Histogram, context info
Global / Rolling shutter
Multi-ROI, MIMR, SIMR
Defect correction, HDR
Output 8 or 10 bits //
3.3 / 1.8 power supply
< 200 mW, < 200 µW stby
BII3 PROJECT

BASIC PROCESS

1. CMOS process
2. Handler bonding
3. Back Side Thinning (CMOS bulk removing)
4. BS Bonding pad re-construction
In Night Vision, the amount of light provided by the light from the moon or stars is so small that the overall imaging system is designed not to lose any photon, including the use of wide lenses down to f/1. The consequence is the occurrence of vignetting which can be overcome with the implementation of the BI technology.
BII3 PROJECT

⇒ COMPARISON OF VIGNETTING
⇒ Uniform light, F/1

FI (µlens)  BI
IMAGE QUALITY METRIC

- **Signal-to-Noise Ratio (Standard ISO 12232)**
  - Acceptable images: SNR = 10 (20 dB)
  - Excellent images: SNR = 40 (32 dB)
  - Doesn’t account for the resolution of elementary patterns composing the image.

- **Minimum Resolvable Contrast (MRC)**
  - Noise and MTF performance of a system combined with the human eye characteristic
  - Subjective measurement of a snapshot image of 1951 USAF Contrast Resolution Chart
  - Can be modeled but in practice it is a live measurement.

- **Signal-to-Noise Ratio versus spatial frequency**
  - Combination of Noise, MTF and QE
  - Same criteria of ISO 12232
  - Can be modeled
⇒ Quantum Efficiency $QE(\lambda)$: ratio between the number of collected electrons and quantity of incoming photons $\Phi$.

⇒ $MTF(\lambda, \nu)$ Modulation Transfer Function occurring with the spatial frequency ($\nu$) of the input light which wavelength is $\lambda$.

⇒ Signal noise, result of shot noise $\Phi.QE(\lambda)$ and floor noise $\sigma_n^2$ contribution

$$SNR(\nu) = \frac{\phi.QE(\lambda).MTF(\lambda, \nu)}{\sqrt{\phi.QE(\lambda) + \sigma_n^2}}$$
IMAGE QUALITY METRIC

- Log-sin Chart (input)

- Log-sin and MTF

- SNR(ν) (best case for 100 e-, QE=100%, noise floor = 0)
MEASUREMENT RESULTS

→ Noise floor 3.2 e- (300K)
→ QE, MTF (650nm, 900 nm)
IMAGE QUALITY COMPARISON

⇒ MEASUREMENT RESULTS
→ SNR(ν)

[Graphs showing SNR vs. Spatial Frequency (lp.mm⁻¹) for 650 nm and 900 nm, with curves labeled VIS_FI, VIS_BI, NIR BI, and Ideal case.]
Image quality comparison

- Image of SNR(ν) @ 650 nm (for 100 e-)

(NIR_HI, VIS_HI, NIR_BI, VIS_BI, VIS_HI)
IMAGE QUALITY COMPARISON

Image of SNR(ν) @ 900 nm (for 100 e-)
LIVE IMAGING

⇒ Prototypes Sensors are available for evaluation
⇒ Demonstration kit :
  → GiGE or camera link (full speed output)
  → CIS Full control and image pre-processing (calibration, HDR, ...)

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CONCLUSION

- Back Illuminated CMOS Image Sensor:
  - Up to 90% Quantum Efficiency and high angular response up to 45° compatible with wide aperture lens,
  - BI image quality quantified by SNR(ν) metric,
  - QE and MTF dominant factors for respectively low and high spatial frequencies
Thank you for your attention!