TDI Time Delay Integration Cameras

1. Introduction

2. Technical Features and Applications

3. Conclusion

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What's TDI?

TDI: Time Delay Integration

TDI is a special image acquisition method which realizes high-speed, high-sensitivity and high-resolution.
Introduction

• TDI (Time Delay Integration) is a special image acquisition method which realizes both high-speed and high sensitivity.

An image of object can be accumulated and readout by means of synchronization of CCD vertical transfer with the moving object.

Movement of object
->
Synchronized CCD vertical transfer
->
Exposure accumulation with number of stages.
Introduction

• Principle of operation

- Continuous video image of moving object
- Stack of linear arrays, integrated charge synchronized to the motion
- Significant improved signal to noise ratio
Introduction

• Principle of operation
Introduction

\[ \text{Photon}_\text{SNR}_{\text{TDI}} = \text{Photon}_\text{SNR} \times \sqrt{\text{Nr}_\text{TDI}\_\text{Steps}} \]

Influence of the TDI effect of SNR of the sensor in dependency on photon noise

„like a larger aperture or a lower F-number“

<table>
<thead>
<tr>
<th>Time [nT/s]</th>
<th>Object points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
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<tr>
<td>3</td>
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<td>...</td>
<td></td>
</tr>
<tr>
<td>96</td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td></td>
</tr>
</tbody>
</table>

\[ K = \frac{f}{D} \]

K=F-number
f=focus
D=aperture
**Introduction**

\[ MFT = MTF_{Optics} \cdot MTF_{Pixel} \cdot MTF_{Channel} \cdot MTF_{smear[TDI]} \]

Mechanical stabilisation dependend on the number of integration steps (TDI-stages)

Mechanical stabilisation and accuracy of the sensor controlling give an additional MTF component

Synchronization via external trigger and/or encoder is recommended
Introduction

Modulation Transfer Function of TDI sensor
TDI Sensor structure

Using multiple amplifiers (Tap) permit parallel image readout at a fast line rate
Advantage of TDI operation

Higher sensitivity than conventional line sensor

High sensitivity is realized by repetition of exposure and charge accumulation with number of vertical stages

Higher speed than conventional area sensor

High-speed readout is realized by synchronization of moving object and multi-tap
Unique back-thinned CCD sensor

- Extended spectral response from UV to NIR
- 193nm – 1200nm
- High sensitivity
- more than 90% at VIS
Unique back-thinned CCD sensor

Photo sensitivity / wavelength

(V/µJ cm²) (nm)
Unique back-thinned CCD sensor

Back-thinned sensor

Conventional front-illuminated sensor
Unique back-thinned CCD sensor
Unique back-thinned CCD sensor

e.g. S10201-04

2048 x 128 Pixels

Pixel size: 12µm x 12µm

Effective area: 24.58mm x 1.54mm
Features

- **Back-thinned CCD sensor** for high sensitivity and large spectral range

- **Frame readout mode** for easy focusing and alignment

- **Bi-directional readout** for faster imaging

- **Anti-blooming with lateral overflow drain**
  Overflow charge from saturated pixels can be drained and it can be 100x of saturation level
Frame mode

Area imaging mode

In this mode, the camera alternate between exposure and read out in internal timing. The CCD that is on this camera is full frame transfer type. Therefore, readout time is contained in exposure time. Exposure time is allowed from 5.12 ms to 0.6528 s (7.296 ms steps).
1 line exposure time is defined the numbers of horizontal transfer pulse. Fastest 20 μs and variable 33.3 ns steps.
State of the art manufacturing of TDI chips at Solid State Division
Assembling of TDI cameras at System Division

TDI Time Delay Integration

Hamamatsu Photonics Deutschland GmbH

Photon is our business
ISO certification
Applications

- High-speed imaging for low light applications i.e. fluorescence imaging
- Semiconductor inspection
- Electronics manufacturing and inspection
- High-speed scanning for large size samples i.e. flat panel displays
- Continuous imaging of high-speed moving object i.e. satellite imaging
- High-speed quality inspection of tapes
- Glass sorting with glass recycling applications
Applications

100% Si-Wafer inspection

Detection of voids on and inside Si-wafers
Applications

High-speed parts inspection

Acquire image with high speed and high sensitivity

High speed motion

フラッシュ照明
Flash illumination

TDIカメラ
TDI camera
Applications

Postal Automation

Fast automatic sorting of letters and parcels
Applications

Glass inspection

Inspect blemish or scratch on a large size glass with high-speed by bi-directional readout
Applications

Fluorescence detection in liquid flow

Observation of fluorescence images and measurement of intensity simultaneously

PMT-system, only intensity measurement
Applications

DNA chip reader

High sensitivity and minimized damage of samples by excitation light
Applications

Virtual Microscope
Fast and high resolution conversion of fluorescence glass slides into digital slides

HAMAMATSU
PHOTONICS DEUTSCHLAND GmbH
Applications

Virtual Microscope
Fast and high resolution conversion of fluorescence glass slides into digital slides
Applications

NanoZoomer Digital Pathology
Fast and high resolution conversion of fluorescence glass slides into digital slides
Applications

Fast and high resolution conversion of fluorescence glass slides into digital slides
Fast and high resolution conversion of fluorescence glass slides into digital slides

TDI Application in Whole Slide Imaging

High Resolution Epi-Fluorescence

Slide Loader

High Sensitivity TDI Sensor

X-Y-Z Motorized Stage
Applications

NanoZoomer Digital Pathology
Fast and high resolution conversion of fluorescence glass slides into digital slides

Resolution: 0.23µm / pixel
Scanning range: 25mm x 52mm
Objective lens: x20, N.A. 0.7
Scanning time: 3 min (20mm x 20mm)
Applications

Glass recycling
Glass sorting for glass recycling

- UV light for separation of different glass materials
Applications

Glass sorting for glass recycling

- UV light for separation of different glass materials
C10000 TDI-Camera
Model -201

2048 x 128 pixels

Pixel clock rate: 30 MHz

TDI-line rate: 0.45 kHz – 50 kHz

Full well capacity: 100 000 e⁻

Dynamic range: 770 : 1

A/D conversion: 12 bit / 8bit

External trigger

CameraLink
C10000 TDI-Camera
Model -301, -401

1024 x 128
2048 x 128 pixels

Pixel clock rate: 30 MHz
TDI-line rate: 0.45 kHz – 50 kHz
Full well capacity: 100 000 e⁻
Dynamic range: 667 : 1
A/D conversion: 12 bit / 8bit
CameraLink
DSP for real-time shading correction
C10000 TDI-Camera Model -601, -701

4096 x 128 pixels

Binning: 2x2

Pixel clock rate: 30 MHz

TDI-line rate: 0.45 kHz – 100 kHz

Full well capacity: 100 000 e-

Dynamic range: 1000 : 1

A/D conversion: 12 bit / 8bit

CameraLink

DSP for real-time shading correction
C9260-921T, C9260-931T

1024 x 58 Pixels – 1024 x 250 Pixels
2048 x 122 Pixels

Pixel clock: 250kHz

TDI line rate: 2.47 Hz – 169 Hz

Back-thinned CCD, cooled 0°C

Full well capacity: 600 000

Dynamic range: 30 000 : 1

16 Bit A/D conversion

IEEE1394 or USB-Interface

External trigger

DCAM-API support
C10650 X-ray TDI-Camera

Microfocus X-ray source

X-ray TDI-camera
C10650 X-ray TDI-Camera

1536 x 128 pixels (2Tap / 3Tap)

Pixel clock rate: 2.5 MHz
TDI-line rate: 38 kHz – 1.43 kHz

FOS Fiber optic plate with scintillator (CsI)

X-ray detection range: 25kVp to 80kVp
X-ray tolerance range: 130kVp, 50W

A/D conversion: 12 bit

CameraLink
DSP for real-time shading correction
C10650 X-ray TDI-Camera

For non-destructive inspection
medicine and drug inspection
print circuit inspection
surface-mounted component inspection
C10650 X-ray TDI-Camera application

Wide imaging area.
Bridged BGA can be seen.
C10650 X-ray TDI-Camera application

Detection of fish bone in the can
(Even small bone can be seen)
C10650 X-ray TDI-Camera application

**Terminal and Staple**

<table>
<thead>
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<th>TDI camera (48 μm)</th>
<th>Line scan camera (200 μm)</th>
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**Stainless Steel Ball**

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<th>Line scan camera (200 μm)</th>
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Comparism between standard line-scan camera and TDI camera
C10000 TDI-Camera

1. Power supply cord
2. CameraLink cable

Hamamatsu Photonics Deutschland GmbH
HiPic Software

For TDI cameras

- Image acquisition and storage
- Frame mode for focusing and positioning
- Sequences
- Image improvement: contrast enhancement, background-subtraction, Shading-correction, mathematic functions
- Analysis-functions: intensity-profile, point-intensity, distance measurement, histogram
- Camera-control functions: exposure time, binning, gain-offset
HiPic Software

TDI Time Delay Integration

Hamamatsu Photonics Deutschland GmbH
Conclusion

TDI Time Delay Integration cameras for

- High-speed imaging of moving objects
- Low light conditions
- High resolution, high sensitivity, 128 TDI stages for better images
- Large spectral range from UV-NIR, X-ray
- Comprehensive hard- and software support, SDKs for developers
- State-of-the-art wafer fabrication

For

Industrial & Bio-Medical-applications
Where is HAMAMATSU
Manufacturing...

3 Divisions

Solid State Division

Electron Tube Center

Systems Division
TDI Time Delay Integration

Hamamatsu Photonics Deutschland GmbH - location
Subsidiary of Hamamatsu Photonics
Founded in 1986

Main Office in Herrsching
near Munich

Sales Group
Technical Support Group

ISO 9001 certified

65 Employees

Revenue 32 Mio €
HAMAMATSU Photonics Deutschland

new building

December 2004
Thank you very much

And see you at our stand 6 B 11

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