A Modular Approach

Spectroscopy Solutions

A Modular Approach
Andor Spectroscopy
Product Portfolio

Engineered from the outset with “ease-of-use” in mind, every Andor spectroscopy system features a combination of market leading detectors and spectral instruments, seamlessly controlled through Andor’s dedicated and intuitive Solis software platform. From configuration of these pre-aligned, pre-calibrated instruments to integration into each unique laboratory set-up, Andor spectroscopy solutions allow researchers around the world to focus quickly on their own challenges: achieving high quality results and breakthrough discoveries.

1 Detectors
Market leading CCDs, InGaAs PDAs, Intensified CCDs and Electron-Multiplying CCDs for VUV to NIR spectroscopy. Unsurpassed combination of cutting-edge Thermo-Electric cooling, proprietary vacuum technology and ultra-low-noise electronics to extract the very best performance from every Andor camera.

2 Spectrographs
Complete family of rugged, pre-aligned and pre-calibrated Czerny-Turner, Echelle and transmission spectrographs, for applications ranging from high-resolution UV plasma studies to NIR photoluminescence. The ideal partner for Andor’s high-performance detectors and accessories for ultimate low-light detection.

3 Accessories
From gratings to fibre optics, sample chambers and filter wheels, each accessory offers seamless optimization of Andor detection system performance and easy integration into researchers’ complex experimental setups. Andor also offers a range of single point detectors including PMTs, Si photodiode, InGaAs, PbS, InSb and MCT for extension into the Short and Long-Wave IR.

4 Micro-spectroscopy
Modular, seamlessly upgradable micro-spectroscopy solutions. Large range of microscope coupling accessories including direct C-mount and ‘cage’ system, microscope height matching feet set and spectrograph wide-aperture slit for large field imaging of sample and spectroscopy analysis through the same optical path.

5 Software
Solis Spectroscopy and Solis Scanning offer interactive and dedicated graphical interfaces for simultaneous multichannel or single point detector data acquisition, as well as spectrographs and motorized accessories control.

The new highly modular, compact imaging Shamrock 193i spectrograph is the ideal platform for micro-spectroscopy (Raman, Luminescence/Fluorescence, SHG).

The new iXon Ultra 888 EMCCD boasts a large field of view, high resolution pixels, lightning speed and extremely low light detection capabilities, ideal for photon starved micro-spectroscopy applications.
Our Expertise

Our experience has enabled us to bring together the latest cutting-edge technology in the fields of sensors, electronics, optics, vacuum technology and software to deliver world-class, market-leading scientific spectroscopy detection systems. Andor’s experience in manufacturing high-performance spectroscopy systems spans over 25 years, with thousands of detectors in the field and a proud history of remarkable advances in a wide variety of research areas, truly helping scientists all over the world to “Discover new ways of seeing”.

A Charge Coupled Device, or CCD, is a 2D matrix of silicon diode photo-sensors referred to as “pixels”. Incident photons with sufficient energy are absorbed in the silicon bulk and liberate an electron, which can be stored and detected as part of a readout sequence. Photons with wavelength >1.1 μm do not have enough energy to create a free electron and therefore set the upper detection limit of silicon CCDs.

The probability of detecting a photon at a particular wavelength is known as Quantum Efficiency (QE). QE will vary with depletion depth of the silicon, quality of the CCD structural layers and clocking electrodes “transparency”.

At the end of an exposure, the CCD pixel charges are transferred sequentially under a masked area known as the shift register. This serial register connects to an amplifier that digitizes the signal and allows a quantitative readout of the amount of electrons per pixel.

The principal types of high performance CCD-based digital cameras include:
- The Charge-Coupled Device (CCD)
- The Electron Multiplying CCD (EMCCD) with on-chip gain for sensitivity down to a single photon
- The Intensified CCD (ICCD) - Image Intensifier provides fast nanosecond optical shuttering and signal amplification

Unless protected, cooled CCD, EMCCDs or InGaAs sensors will condense moisture, hydrocarbons and other gas contaminants. Exposed to such outgassed contaminants when cooled, the Quantum Efficiency of sensors will decline proportionally. Andor’s Ultravac™ offers the following benefits:
- Maintenance-free operation in laboratory or in-field over extended periods of time, unlike liquid nitrogen (LN2) cooled platforms that require hazardous and regular manual Dewar refills.
- Operating temperatures of the chip can be reduced significantly. Better cooling with an enhanced thermoelectric (TE) Peltier design translates into substantially lower darkcurrent and fewer “hot” blemishes.
- No peak QE and sensor cooling performance degradation over many years operation. Andor Ultravac™ technology offers an MTBF (mean time between failure) of more than 100 years.

A camera Signal-to-Noise Ratio (commonly abbreviated to S/N or SNR) is the true comparison basis between detectors and detector technologies. It takes into account both the photon capture capability of the detector and the different noise sources along the detection path that can impact on the integrity of the useful signal. The sources of this noise are the following:

- Readout noise
- Inherent sensor electron-to-voltage conversion and amplification noise
- Thermal noise
- Originating from sensor, blackbody radiation (SWIR region) or image intensifier photocathode
- Photon noise / Shot noise
- Statistical incoming photon variation
- Spurious Charge / Clocking Induced Charge (CIC)
- Result of impact ionization during charge transfer

$$\text{Noise}_{\text{total}} = \sqrt{N_{\text{readout}}^2 + F^2 G^2 (N_{\text{amplification}}^2 + N_{\text{photons}}^2 + N_{\text{CIC}}^2)}$$

F = amplification noise factor
G = amplification gain

CCD Sensitivity is shot noise and readout noise limited - typically used at slow digitization speeds
EMCCD Sensitivity is shot noise and CIC limited – typically used for photon-starved and ultrafast spectroscopy
ICCD Sensitivity is shot noise and photocathode thermal noise (EBI) limited – typically used for ns time-resolution

Making sense of sensitivity: signal-to-noise ratio considerations
Andor has been taking pride in helping researchers around the world achieve breakthrough discoveries for the last 20 years. By keeping at the forefront of detector technology, Andor is able to offer a range of market leading high-performance, ultra sensitive spectroscopy detectors. Our CCDs, ICCDs, EMCCDs and InGaAs arrays can operate from the VUV to Near-Infrared spectral regions with a unique combination of high sensitivity (down to single photon in the case of EMCCD technology) and ultrafast acquisition speeds.

**Spectroscopy Cameras**

A two dimensional silicon-based semiconductor matrix of photo-sensors, with sensitivity ranging from soft X-ray to NIR (1.1 μm). Spectroscopy CCDs are traditionally a rectangular format with a maximum width of 30 mm and a height up to 13 mm, i.e. matching the focal plane size of the majority of high-end spectrographs.

**InGaAs**

Short Wave IR Spectroscopy

Indium Gallium Arsenide (InGaAs) is a photo-sensitive material used for detection up to 2.2 μm. The typical sensor architecture for spectroscopy applications is a single row array of up to 26.6 mm.

**Intensified CCD**

Nanosecond Time Resolution

Combination of a CCD matrix with a fibre coupled Image Intensifier, which provides optical shuttering capabilities and time-resolution down to the nanosecond regime while also offering a signal amplification up to x100.

**Applications**

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<tr>
<td>BV</td>
<td>Back-illuminated, deep depletion, high sensitivity with fringe suppression</td>
</tr>
<tr>
<td>BVX2 AU</td>
<td>Back-illuminated, deep depletion, ultra-broadband dual AR coating with fringe suppression</td>
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<tr>
<td>BVX</td>
<td>Back-illuminated, deep depletion, high sensitivity with fringe suppression</td>
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<tr>
<td>BU</td>
<td>Back-illuminated, UV-enhanced, 400 nm optimized</td>
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<tr>
<td>BU2</td>
<td>Back-illuminated, UV-enhanced, 200 nm optimized</td>
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<td>BV</td>
<td>Front-illuminated, low dark current</td>
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<td>FI</td>
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**Electron Multiplying CCD**

High Sensitivity and Speed

Identical architecture to standard CCD sensors, with the addition of an on-chip amplification channel prior to the digitisation node, designed to overcome the readout noise limitation of slow-scan CCDs. This revolutionary technology opens the door to ultra-sensitive and ultra-fast spectroscopy.

**Intensified CCD**

Nanosecond Time Resolution

Combination of a CCD matrix with a fibre coupled Image Intensifier, which provides optical shuttering capabilities and time-resolution down to the nanosecond regime while also offering a signal amplification up to x100.

**CCD**

Workhorse Broadband Platform

Identical architecture to standard CCD sensors, with the addition of an on-chip amplification channel prior to the digitisation node, designed to overcome the readout noise limitation of slow-scan CCDs. This revolutionary technology opens the door to ultra-sensitive and ultra-fast spectroscopy.

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The iDus is Andor’s most popular platform for the spectroscopy research and OEM communities, suitable for everyday spectroscopy measurements, as well as more advanced, low light detection applications.

Comprehensive Sensor Range

CCD matrix sizes include 1024 x 127, 1024 x 256 and high resolution 2000 x 256 formats with UV and NIR optimized options. Dual AR coating (BEX2-DD) offers the best broadband detection performance and versatility.

High Sensitivity

Best detection capabilities for experiments requiring long exposure times. The iDus range boasts sensor QE option up to 95%, TE cooling down to -100°C and state-of-the-art Ultravac™ for long-lasting performance. New Low Dark Current Deep-Depletion (LDC-DD) technology offers the best detection capabilities in the near infrared.

Key Applications

- Absorption
- Transmission
- Reflection
- Raman (244, 532, 785 and 833 nm)
- Fluorescence - Luminescence - Photoluminescence
- Plasma studies
- Pharmacology

Benefits

- High detector sensitivity options both in VIS and NIR regions
- Negligible dark current without the inconvenience of LN₂ cooling
- Permanent vacuum integrity, critical for deep cooling and best sensor performance
- Choice of high dynamic range (401 and 420 models) or high resolution (416 model)
- Greatly reduces etaloning effect above 650 nm
- High NIR QE, low etaloning – ideal for NIR Raman or photoluminescence. Superior broadband detection with Dual-AR technology option (BEX2-DD). Low-dark-current (LDC) technology (416 model) – ideal for challenging low light NIR spectroscopy without the need for LN₂ cooling
- Readily integrate with Andor Shamrock spectrograph series

Features

- Peak QE of 95%
- TE cooling to -100 °C
- Ultravac™ – Guaranteed hermetic vacuum seal
- 26 or 15 μm pixels
- Fringe suppression technology for back-thinned and back-illuminated Deep-Depletion option
- Deep-Depletion sensor options

More information at andor.com/learning

Webinar
"Investigating Molecular Properties of Live Cells and Tissues"

Technical Notes
"LDC-DD technology for high sensitivity NIR spectroscopy"
"Ultravac technology and long-lasting detection performance"

Model

<table>
<thead>
<tr>
<th>Model</th>
<th>Active pixels (μm)</th>
<th>Pixel size (μm)</th>
<th>Deepest cooling</th>
<th>Sensor options</th>
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<tr>
<td>DU416</td>
<td>2000 x 256</td>
<td>15 x 15</td>
<td>-90°C</td>
<td>LDC-DD</td>
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<tr>
<td>DV416</td>
<td>2000 x 256</td>
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<td>LDC-DD</td>
</tr>
<tr>
<td>DU401</td>
<td>1024 x 127</td>
<td>26 x 26</td>
<td>-100°C</td>
<td>BU, BV</td>
</tr>
<tr>
<td>DU416-BR-DD</td>
<td>1024 x 128</td>
<td>26 x 26</td>
<td>-100°C</td>
<td>BEX-DD, BU, BV, OE, BVF</td>
</tr>
<tr>
<td>DU420</td>
<td>1024 x 255</td>
<td>26 x 26</td>
<td>-100°C</td>
<td>BU, BV, OE</td>
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iDus InGaAs

Andor’s platform for large bandpass SWIR spectroscopy

The iDus InGaAs range is a perfect complement to Andor’s UV-VIS-NIR CCD camera family, extending spectral detection capabilities beyond 1.1 μm and up to 2.2 μm.

Choice of Resolution and Bandpass
Both 1.7 and 2.2 μm cut-off option offer high resolution and high capacity pixel sizes (25 and 50 μm respectively) and large band-pass option (1024 pixels / 25.6 mm width) for extended spectral information simultaneous collection.

TE cooling - No need for inconvenient use of LN₂
The Thermo-Electrically cooled, in-vacuum sensors reach cooling temperatures of -90°C where the best signal-to-noise ratio can be achieved for the majority of the applications in this spectral region. Beyond this cooling point blackbody radiation from any elements facing the sensor will dominate the dark signal, and since Quantum Efficiency will be impacted with decreasing cooling temperature, TE cooling will allow access to optimum SNR performance.

Key Applications
- NIR and SWIR absorption
- Transmission - Reflection
- Raman (1064 nm)
- Near Infrared Modulation

Features
- High Quantum Efficiency
- Peak QE >80% for 1.7 μm cut-off
- Peak QE >70% for 2.2 μm cut-off
- Typically attainable TE cooling to -90°C
- Minimum exposure time of 1.4 μsec
- 25 μm pixel width option
- 25.6 mm wide arrays options
- Software selectable output amplifiers
- Simple opto-mechanical coupling interface
- Simple USB 2.0 connection

Benefits
- Maximum sensitivity in the SWIR
- Minimise dark current efficiently without the inconvenience of LN₂
- Ensures best sensor performance and protection in time
- Allows study of fast transient phenomena
- Optimized for high dynamic range and high resolution
- Optimized for Czerny-Turner spectrograph focal plane size
- Choice of High Dynamic Range (HDR) or High Sensitivity (HS)
- Readily integrates with Andor Shamrock spectrograph series
- User-friendly plug and play connection directly to the back of the camera

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Model Array size (mm) Array size (pixels) Pixel size (W x H, μm) Upper cut-off wavelength (μm)
DU490A-1.7 12.8 512 x 1 25 x 500 1.7
DU490A-2.2 12.8 512 x 1 25 x 250 2.2
DU491A-1.7 25.6 1024 x 1 25 x 500 1.7
DU491A-2.2 25.6 1024 x 1 25 x 250 2.2
DU492A-1.7 25.6 512 x 1 50 x 500 1.7
DU492A-2.2 25.6 512 x 1 50 x 250 2.2
Newton CCD

The world’s fastest spectroscopy CCD

When it comes to access simultaneously the best spectral resolution, acquisition rates and detection range flexibility, the Newton CCD cameras always come first.

Fast spectral acquisitions
The Newton MHz readout platform allows spectral rates up to 1,600 spectra per second with crop mode, ideal for fast micro-spectroscopy chemical mapping or microfluidics analysis.

High resolution and high dynamic range spectroscopy
13.5 µm pixel option allows access to the highest spectral resolution, while 26 µm pixel matrix boasts larger photoelectrons storage capacity and greater dynamic range.

Key Applications
Absorption - Transmission - Reflection
Raman (244, 532, 785 and 833 nm)
Fluorescence - Luminescence - Photoluminescence
Plasma studies
Plasmonics
Fast transient phenomena study

Features
- Multi-megahertz readout
- TE cooling to -100°C
- UltraVac™ - guaranteed hermetic vacuum seal technology
- Down to 13.5 x 13.5 µm pixel size
- Crop mode operation
- Deep-oxidation sensor options
- Software-selectable output amplifiers (DU940)
- Simple opto-mechanical coupling interface
- Simple USB 2.0 connection

Benefits
- High repetition rates achievable with low noise electronics - ideal for transient phenomena study
- Negligible dark current without the inconvenience of LN₂
- Permanent vacuum integrity, critical for deep cooling and best sensor performance access
- Achieve the highest possible spectral rates of over 1,600 spectra per second
- High NIR QE, virtually etalon-free - ideal for NIR Raman
- Superior broadband detection with Dual-AR technology option (BEX2-DD)
- Choice of High Dynamic Range (HDR) or High Sensitivity (HS)
- Readily integrate with Andor Shamrock spectrograph series
- User-friendly plug and play connection directly to the back of the camera

More information at andor.com/learning

Application Note
Fibre Probes Based Raman spectroscopy Bio-sensor for Surgical Robotics

Model | Active pixels (µm) | Pixels size (µm) | Sensor options
--- | --- | --- | ---
DU920 | 1024 x 255 | 26 x 26 | BU, BU2, BV, OE, BVF
DU920-BX-DD | 1024 x 256 | 26 x 26 | BU, BU2, BV, OE, BVF
DU940 | 2048 x 512 | 13.5 x 13.5 | BR-DD, BEX2-DD
DU920-BX-DD | 2048 x 512 | 13.5 x 13.5 | BR-DD, BEX2-DD
From the pioneers of EMCCD technology the newly expanded iXon Ultra and Newton™ series have brought low-light spectroscopy to a new level of performance. These cameras offer the absolute combination of sensitivity and acquisition speed for the most demanding photon starved applications.

**Highest sensitivity**
EMCCDs operate by amplification of weak signal events (down to single photons) to a signal level that is well clear of the read noise floor of the camera at any readout speed. This ‘on-chip’ amplification process is realized without sacrificing the photon collection capability of the sensor. Back-illuminated architecture boosts QE up to 95%, while Andor’s market leading TE cooling to -100°C offers unmatched dark noise performance.

**Highest spectral rates**
The supercharged iXon Ultra and Newton™ allow access to the highest spectral rates without loss of sensitivity thanks to the EM amplification architecture. The iXon Ultra 888 achieves over 11,000 spectra per second (Crop Mode), while the Newton 970 allows spectral rates in excess of 1,515 spectra per second (Crop Mode) with larger simultaneous bandpass capture capabilities.

**Features**
- <1 e- readout noise and up to 90% QE
- Industry benchmark for fast frame and spectral rate
- Cropped mode option
- Ultravac™ technology and TE cooling down to -100°C
- Software-selectable output amplifiers
- Spectroscopy and Imaging sensor formats available
- Seamless integration with Andor spectrographs
- Simple USB 2.0 connection
- More information at andor.com/learning
- Webinar: EMCCDs for spectroscopy
- Application note: Spectral Flow Cytometry

**Benefits**
- ‘Silent’ noise floor; perfectly complements high QE performance for extremely low-light detection
- Full vertical binning up to 650 spectra per second or imaging frame rate up to 56 full-frames per second
- Boast spectral rates in excess of few thousand of spectra per second
- Permanent vacuum integrity, critical for deep cooling and best sensor performance access
- Choice of High Sensitivity (low light applications) or Electron Multiplication (ultra-low light applications down to single photon)
- 25 mm wide option for maximum spectral information collection, or up to 13 mm tall option for larger vertical field of view, ideally suited for micro-spectroscopy.
- Fringe suppression options available for minimizing optical etaloning above 650 nm
- Simple opto-mechanical coupling to Andor Shamrock spectrograph series, with all-integrated dedicated software control
- User friendly plug and play connection directly to the back of the camera

**Model** | **Active pixel matrix** | **Pixel size (μm)** | **Fastest spectral rate** | **Data transfer interface** | **Sensor options**
--- | --- | --- | --- | --- | ---
Newton 970 | 1650 x 200 | 16 x 16 | 1.515 sps | USB 2.0 | BV, UV, UVB, BVF
Newton 971 | 1650 x 400 | 16 x 16 | 1.515 sps | USB 2.0 | BV, UV, UVB
iXon Ultra 888 | 1024 x 1024 | 13 x 13 | 11,990 sps | USB 3.0 | BV, UBV, EXP, EX
iXon Ultra 897 | 512 x 512 | 16 x 16 | 9,921 sps | USB 2.0 | BV, UBV, EXP, EX, BVF

Professor Michael Morris
Professor of Chemistry, University of Michigan

“In our lab the Andor NewtonEM EMCCD has enabled millisecond Raman spectroscopy and hyper-spectral Raman imaging in times as short as a minute or two. And the 1600 x 400 format is just right for spectroscopy.”
iStar ICCD

Industry gold standard for high-resolution, high-speed nanosecond time-resolved spectroscopy

With over 16 years of Excellence in the development of world-class, fast-gated intensified CCD cameras, Andor’s iStar detectors are at the forefront of rapid, nanosecond time-resolved spectroscopy. It extracts the very best from CCD sensor and gated image intensifier technologies, achieving a superior combination of rapid acquisitions rates and exceptional sensitivity down to single photon.

Nanosecond time-resolution
Software-controlled, ultra-low-jitter onboard Digital Delay Generator (DDG™) and high-voltage, high-speed gating electronics offer < 2 ns time resolution and ultra-precise synchronisation.

Highest spectral rates
The iStar’s 5 MHz platforms and Intelligent Crop and Fast Kinetics modes offer spectral rates in excess of 3,500 sps and 9,525 sps respectively.

More information at andor.com/learning

Professor JJ Laserna
Professor of Chemistry, University of Malaga

“The Andor iStar ICCD detectors played a vital role in allowing us to develop this new mobile standoff detection system since their sensitivity allowed us to work with exceedingly low light levels. Furthermore, their refresh rates meant we could analyze spectral information at rates in excess of 10 Hz and, therefore, perform simultaneous Raman and LIBS spectroscopy in real time.”

Key Applications
- Stand-off LIBS - A detection technique for explosive residues
- High sensitivity imaging of Thomson scattering signal

Application Notes
- “Intelligent and accurate MCP gating for better than 1:107 shuttering efficiency in the UV
- Software-controlled 3x triggering outputs with 10 ps setup accuracy
- Compressive triggering interface
- Intelligent and accurate MCP gating for better than 1:107 shuttering efficiency in the UV
- Efficient minimization of CCD dark current and pixel blemishes

Features
- USB 2.0 connectivity
- 5 MHz readout platform
- Comprehensive binning options - Crop and Fast Kinetic mode
- High-resolution sensors and image intensifiers
- High QE Gen 2 and 3 image intensifiers
- True optical gating < 2 ns
- Low jitter, on-board digital delay generator
- Insertion delay as low as 19 ns
- Comprehensive triggering interface
- Intelligent and accurate MCP gating for better than 1:107 shuttering efficiency in the UV
- TE-coding to -40°C
- Real-time control interface

Benefits
- Industry-standard plug and play, lockable and rugged interface
- Seamless multi-camera control from single PC or laptop
- Rapid spectral rates for superior dynamic phenomena characterization
- Fully software-customizable binning sequences for highest spectral and image rates. Greater than 3,400 spectra/s continuous rates, up to 29,000 spectra/s in burst mode
- Sharpest images and spectral definition, 100% fill factor for maximum signal collection
- Highest intensifier resolution with QE > 50% and sensitivity up to 1.1 μm
- Lowest delay from signal generation to photocathode triggering
- Software-controlled 3x triggering outputs with 10 ps setup accuracy
- Maximizes signal-to-noise in high repetition rate laser-based applications
- Efficient minimization of CCD dark current and pixel blemishes
- On-the-fly software control of intensifier gain, gating and 3x outputs trigger parameters for real-time detection optimization

Models | Active Pixel Matrix | Effective Pixel Size (μm) | Image Intensifier Choice (optical taper) |
--- | --- | --- | --- |
DH820T | 1024 x 256 | 26 x 26 | Q16 mm [1:1] Q25 mm [1:1] |
DH334T | 1024 x 1024 | 13 x 13 | Q16 mm [1:1] Q25 mm [1:1] |
DH340T | 2048 x 512 | 13.5 x 13.5 | Q16 mm [1:1] Q25 mm [1:1] |

Quantum Efficiency (QE) (%)

<table>
<thead>
<tr>
<th>Gen</th>
<th>Type</th>
<th>Coverage (nm)</th>
<th>Peak QE (typical)</th>
<th>Minimum gating speed (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Gen 2</td>
<td>180-850</td>
<td>18%</td>
<td>&lt; 2 ns</td>
</tr>
<tr>
<td>3</td>
<td>Gen 3</td>
<td>180-910</td>
<td>25%</td>
<td>&lt; 100 ns</td>
</tr>
<tr>
<td>4</td>
<td>Gen 4</td>
<td>180-850</td>
<td>18%</td>
<td>&lt; 2 ns</td>
</tr>
<tr>
<td>5</td>
<td>Gen 5</td>
<td>180-850</td>
<td>16%</td>
<td>&lt; 5 ns</td>
</tr>
<tr>
<td>3</td>
<td>Gen 3</td>
<td>180-910</td>
<td>13.5%</td>
<td>&lt; 50 ns</td>
</tr>
<tr>
<td>2</td>
<td>Gen 2</td>
<td>280-760</td>
<td>44%</td>
<td>&lt; 2 ns</td>
</tr>
<tr>
<td>1</td>
<td>Gen 1</td>
<td>280-910</td>
<td>26%</td>
<td>&lt; 2 ns</td>
</tr>
</tbody>
</table>

Photo-cathode | Type | Coverage | Peak QE (typical) | Minimum gating speed (ns) |
--- | --- | --- | --- | --- |
| InGaAs | Gen 3 | 280-910 | 13% | < 100 ns |
| InGaAsP | Gen 4 | 280-910 | 26% | < 100 ns |
| InGaAs | Gen 5 | 180-850 | 25% | < 100 ns |
| InGaAsP | Gen 6 | 180-850 | 18% | < 2 ns |
| InGaAs | Gen 7 | 180-850 | 16% | < 5 ns |
| InGaAsP | Gen 8 | 180-850 | 13.5% | < 50 ns |
| InGaAs | Gen 9 | 280-760 | 44% | < 2 ns |
| InGaAs | Gen 10 | 280-910 | 26% | < 2 ns |
Andor technical know-how extends far beyond market-leading performance detectors with a comprehensive range of high-end spectrographs. At the heart of this portfolio is the Shamrock family, which offers ultimate flexibility and performance with its “out-of-the-box”, pre-aligned and pre-calibrated approach and seamless combination with Andor’s highly sensitive spectroscopy cameras. The Mechelle 5000 is Andor’s dedicated detection solution for broadband and high resolution LIBS.

**Spectrographs**

**Shamrock 163**
Rugged, compact 163 mm focal length manual spectrograph, highly configurable for general, everyday lab spectroscopy.

**Shamrock 193i** NEW
Andor’s latest intelligent, modular and compact imaging spectrograph with Active Focus technology, fully motorized, FPD-haged dual grating turret, dual detector output ports and seamless interfacing to microscopes for modular micro-Raman or micro-luminescence setups.

**Shamrock 303i**
Laboratory workhorse platform with plug and play USB interface, fully motorised triple grating turret, slits and filter wheel and imaging-optimized optics for multi-track spectral acquisition.

**Shamrock 500i**
Ideal combination of high spectral resolution, imaging capabilities for multi-track acquisitions and monochromator capabilities with single point detector use for detection up to 12 µm. Converts to USB interface, fully motorized platform and accessory range.

**Shamrock 750**
Delivers the highest spectral resolution of the Shamrock range with plug and play USB interface, fully motorized multi-track acquisition platform and accessory range.

**HoloSpec F/1.8**
Patented optical echelle design with band-pass ranging from 200 nm to 975 nm and resolution power λ/Δλ of 5,000 across the full wavelength range, all accessible in a single acquisition without the need for moving components.

**Mechelle 5000**
High throughput spectrograph with superb high-density multi-track spectroscopy capabilities. Robust and compact design based on low stray-light transmission virtual phase holographic (VPH) grating.

**Applications**

<table>
<thead>
<tr>
<th>Shamrock series</th>
<th>Shamrock 163</th>
<th>Shamrock 193i</th>
<th>Shamrock 303i</th>
<th>Shamrock 500i</th>
<th>Shamrock 750</th>
<th>HoloSpec F/1.8</th>
<th>Mechelle 5000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorption - transmission - reflection</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
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<tr>
<td>Photoluminescence - fluorescence</td>
<td>•</td>
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<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Raman (SERF, SOFS, CARS, Stimulated)</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Micro-Raman</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
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<tr>
<td>Micro-fluorescence</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Photon counting</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
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<tr>
<td>Single molecule spectroscopy</td>
<td>•</td>
<td>•</td>
<td>•</td>
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<td>•</td>
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<tr>
<td>LIBS</td>
<td>•</td>
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<td>•</td>
<td>•</td>
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<td>•</td>
</tr>
<tr>
<td>Plasma studies</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Multi-track spectroscopy</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
</tbody>
</table>

* • Suitable  ** • Optimum
Versatile, intelligent and compact imaging spectrograph

Andor’s latest addition to the Shamrock family is a compact imaging spectrograph with F/3.6 aperture which, when combined with Andor’s world-class range of ultra-sensitive UV-NIR and SWIR detectors, offers a ‘workhorse’ spectroscopy platform with superb photon collection efficiency.

Adaptive Focus Technology

“Intelligent” motorized adaptive focus allows access to the very best spectral resolution performance in any configuration with un-matched repeatability.

Ease of use

The RFID-tagged, indexed dual-grating turret, dual output port and extensive accessories range provide a highly configurable, yet compact platform to best match Academic and OEMs specific performance requirements.

Key Applications

- Absorption - Transmission - Reflection (UV-NIR and SWIR)
- Raman (244, 532, 785, 833 and 1064 nm)
- Fluorescence - Luminescence (UV-NIR and SWIR)
- Micro-Fluor and Micro-fluorescence
- Photon counting
- Single molecule spectroscopy

Features

- 193 mm focal length
- F/3.6 aperture
- USB 2.0 and i2c interface
- Dual output port
- Motorized dual grating turret

Benefits

- Provides typical resolution of 0.21 nm with a 1200 l/mm @ 500 nm and up to 0.1 nm with a 2400 l/mm grating @ 300 nm
- High throughput design suitable for photon starved applications such as single molecule micro-spectroscopy
- Easy control of both spectrograph and Andor USB detectors through laptops
- Maximum detection flexibility to cover the widest wavelength range by combining UV-Vis-NIR, CCDs with SWIR InGaAs sensor
- Precise indexing design and easy hatch access for rapid in-field upgrade

Adaptive Focus Technology

‘Intelligent’ motorized adaptive focus allows access to the very best spectral resolution performance in any configuration with un-matched repeatability.

Ease of use

The RFID-tagged, indexed dual-grating turret, dual output port and extensive accessories range provide a highly configurable, yet compact platform to best match Academic and OEMs specific performance requirements.

Key Specifications

<table>
<thead>
<tr>
<th>Shamrock 193i</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td>Motorized, USB2.0 and I2C</td>
</tr>
<tr>
<td>Focal length</td>
<td>193 mm</td>
</tr>
<tr>
<td>Resolutions</td>
<td>0.21 nm</td>
</tr>
<tr>
<td>Bandpass</td>
<td>98 nm</td>
</tr>
<tr>
<td>Grating turret</td>
<td>Dual grating, motorized, interchangeable, RFID</td>
</tr>
<tr>
<td>slit options</td>
<td>Adjustable (motorized): 10 µm to 2.5 mm Wide aperture: Motorized 10 µm to 2.5 mm, manual to 15 mm</td>
</tr>
</tbody>
</table>

Looking for a manually-controlled, compact, general benchtop spectroscopy platform?

The Shamrock 163 is a manually controlled, single grating spectrograph designed for setups with lower integration and automation / motorization constraints. More details can be found at andor.com.
Shamrock 303i, 500i and 750

Research grade modular high resolution spectrographs

The Shamrock 303i, 500i and 750 imaging spectrographs are research-grade, high performance, motorized and rugged platforms designed for working with demanding low-light applications, but equally suited to routine measurements.

Versatility

The Shamrock series offers a choice of high resolution, highly modular multi-input and output platforms with a wide range of field-upgradable accessories, including indexed triple grating turrets, motorized slits and filter wheels, shutters, multi-way (multi-track) fibre optics, IR single point detectors, scanning accessories and microscope coupling interfaces.

The right resolution for your experiment

With focal lengths including 303, 500 and 750 mm, researchers have access to a wide range of spectral resolution performance, down to 0.02 nm for plasma spectroscopy or up to a few nanometers for broadband luminescence / photoluminescence spectroscopy. Each Shamrock comes with a choice of three software-selectable gratings (or flat mirror) that offer maximum flexibility with both broadband and high resolution options available at the touch of a button.

Key Applications

- Absorption
- Transmission
- Reflectance
- Raman (244, 532, 785, 833 and 1064 nm)
- Fluorescence
- Luminescence
- UV-NIR and SWIR
- Micro-Raman and Micro-fluorescence
- Protein coating
- Single molecule spectroscopy
- Plasma studies

Features

- Pre-aligned, pre-calibrated detector and spectrograph systems
- Image assignment connection with toroidal optics (303 and 500)
- USB 2.0 interface
- Triple exchangeable grating turret
- Double detector outputs
- Wide range of accessories available
- Monochromator capabilities (500i and 750i)
- Gold and silver optics coating options

Benefits

- Motorized, individually factory-calibrated systems – “out-of-the-box” operation and seamless integration to experimental set-ups
- Maximum light throughput with multitrack capabilities
- Plug and play connectivity, ideal for laptop operation alongside multi-USB camera control
- Precision kinematic mount for precise in-field upgrade
- For extended wavelength coverage when combining Andor UV-NIR CCD and InGaAs cameras
- Extract best optical resolution while allowing use of single point detectors with sensitivity up to 12 μm

Spectrograph Specifications Comparison

<table>
<thead>
<tr>
<th>Feature</th>
<th>303i</th>
<th>500i</th>
<th>750i</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aperture ratio (F/#)</td>
<td>1:4</td>
<td>1:6.5</td>
<td>1:9.9</td>
</tr>
<tr>
<td>Focal length (mm)</td>
<td>303</td>
<td>500</td>
<td>750</td>
</tr>
<tr>
<td>Wavelength Resolution (nm)</td>
<td>0.10</td>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>Band pass (nm)</td>
<td>67</td>
<td>90</td>
<td>28</td>
</tr>
<tr>
<td>Multi-track capability</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

* Nominal values using 1200 l/mm grating, 13.5 μm pixel and 27.6 mm wide sensor, 500 nm central wavelength.

Dr Praveen Ashok
Post-doctoral fellow in the optical manipulation group of University of St. Andrews, Scotland

“While its performance is every bit as good as a bench-top system, the compact size and low weight of the Shamrock 303i lent it a degree of portability as well. This was important to us as we originally developed our Raman spectroscopy bio-sensor to be compatible with a surgical Robotic system.”

More information at andor.com/learning

Accessory Tree
Please refer to p33

Application Note
“Optical spectroscopy in Biomedical research - Non-invasive blood glucose monitoring”

Webinar
“Optofluidic Raman spectroscopy for chemical analysis and Raman spectroscopy bio-sensor for tissue analysis”

Resolution Calculator
andor.com/calculators
HoloSpec F/1.8 and F/1.8i

On-axis high throughput imaging spectrograph

The Andor HoloSpec spectrograph series is the ideal platform for collecting more light and achieving better signal-to-noise ratio faster. Its rugged and compact design makes it an ideal tool for challenging industrial or in-the-field applications, while still offering research-grade performance suitable for academic research.

Superior light gathering power - when every photon counts

The Andor HoloSpec spectrograph series is designed for very high light collection efficiency with a large F/2 aperture and high throughput optical design based on Volume Phase Holographic technology. It provides a perfect match to Andor’s low noise CCD, EMCCD and ICCD detectors, offering the most sensitive and versatile detection solution on the market for Visible or Near-Infrared spectroscopy.

High density multitrack spectroscopy

The on-axis transmission design greatly minimizes scattered light and channel crosstalk when working with high density multi-track fibre optic assemblies, allowing simultaneous acquisition of over 200x individual channels at a time with large area CCDs.

Features

- High collection efficiency ultrathin F/1.8 aperture
- On-axis imaging-corrected design
- High throughput optical design
- Low scattered light
- Compact and rugged design
- Easily interchangeable accessories
- Specialized Raman grating options
- Optional integrated Rayleigh filtering unit

Benefits

- Up to 6.5 times better light collection efficiency than traditional 1/3" in Czerny-Turner designs
- 100% light collection from NA=0.22 fibre optics
- Superb optical aberration correction across a large focal plane for superior spatial resolution and high density, low crosstalk multi-track (multi-fibres) acquisitions
- Gather more photons per pixel for superior signal-to-noise ratio
- Pre-aligned and pre-calibrated, "out-of-the-box" operation, excellent thermal stability and easily transportable
- "Snap-in" accessories, including precision slits and pre-aligned grating assemblies
- Optimized for Stokes/Anti-Stokes, "low-frequency" or "high frequency" Stokes operation, 514.5 to 830 nm laser options
- Fully-enclosed SuperNotch Plus Kaiser filter compartment with user-friendly external adjustment

Key Applications

- Raman, Luminescence and Plasmonics micro-spectroscopy mapping - e.g. bio-samples, carbon nanostructures, light harvesting complex or organic light-emitting diode (OLEDs)
- Micro-Raman - e.g. Quantum Dots, metal nanoparticles
- Standard chemical detection - e.g. explosives or chemical warfare agents
- Microfluidics - e.g. flow cytometry
- Cell line research - e.g. cancer screening

More information at andor.com/learning

Application Notes

- 'Spectral Flow Cytometry expanded to Visible and Near Infrared Fluorescence spectroscopy'
- 'Hyphenated Raman - OCT Clinical Diagnosis of Skin Cancers'

Resolution and Bandpass

<table>
<thead>
<tr>
<th></th>
<th>F/1.8(i) VIS</th>
<th>F/1.8(i) NIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution (nm)</td>
<td>0.17</td>
<td>0.3</td>
</tr>
<tr>
<td>Bandpass (nm)</td>
<td>32</td>
<td>32</td>
</tr>
</tbody>
</table>

*1 With 50 µm input slit and 13.5 µm pixel CCD e.g. Newton DU940
*2 With 27.6 mm wide CCD e.g. Newton DU940
*3 With 785 nm low frequency grating
*4 With "785 nm low frequency" grating

Image and cross-section of a high density 19 x 100 µm core (125 µm inc. cladding) fibre optics bundle at the output focal plane of a HoloSpec F/1.8 "visible" model. Source is a broadband Deuterium-Tungsten captured from 532 - 609 nm with a Newton EMCCD DU971P-BV.
Mechelle 5000

High-bandpass echelle spectrograph

Andor’s Mechelle 5000 spectrograph is based on the echelle grating principle with a patented optical design providing extremely low crosstalk and maximum resolution compared with other spectrographs. It is designed to operate with both Andor’s iKon CCD camera and the iStar DH334T intensified camera in applications including LIBS and plasma studies.

Key Applications
- Laser Induced Breakdown Spectroscopy (LIBS)
- Plasma studies

Features
- Compact and robust design with no moving components
- Patented optical design
- Auto-temperature correction
- N2 purged
- Pre-aligned detector/spectrograph solution
- Low F/number
- Wide range of accessories available

Benefits
- Ideal for lab and OEM system integration
- Ensures maximum resolution and extremely low cross-talk
- Corrects for the variation of prisms optical refractive index with temperature
- Enables maximum throughput in the UV region
- Enables fast and efficient experimental setup
- Highly efficient light collection
- Including fibre optics, slits, aiming laser, collector/collimator and calibration lamps

Spectrogram Specifications
- Wavelength range (nm) 200 – 975
- Focal length (mm) 195
- Spectral resolution (λ/Δλ) (corresponding to 3 pixels FWHM) 6,000
- Wavelength accuracy Better than ± 0.05 nm
- Optical adjacent order cross-talk Better than 1 x 10⁻²
- Stray light Better than 1.5 x 10⁻⁴

More information at andor.com/learning

Application Note
‘Automated 2D elemental mapping by Laser-Induced Breakdown Spectroscopy’
“Modularity” is Andor’s ethos when it comes to spectroscopy systems, because every researcher’s requirements are unique. This translates into the need for an extensive range of state-of-the-art accessories, from light collection to signal analysis and detection.

Andor combines over 25 years of expertise in the fields of optics, mechanics and electronics, from designing complex interfaces to extract the very best of its market leading detectors and spectrographs, to working alongside key suppliers worldwide. The result is Andor’s ability to offer a comprehensive range of high performance dedicated or extremely versatile accessories, ranging from multi-cord fibre optics to sample chamber, light sources, gratings, slits and third party instruments interfaces including microscope and VUV monochromators.

**Spectral information tailoring**
Selection of low and high density gratings with blaze from UV to NIR, interchangeable fixed, manual and motorized slits, mechanical shutters and filter wheels that accommodate neutral density, Raman edge and long/short pass types.

**Signal input coupling interfaces**
Range of opto-mechanical couplers including fibre optics X-Y adjusters, F/number matchers, sample chamber and UV to NIR-optimized lenses. Andor’s portfolio for modular micro-spectroscopy includes C-mount compatible flanges, wide-aperture slit, modular cage systems and a range of microscope test for optical height matching.

**Light sources**
Spectral calibration lamps including “pen-ray” style Mercury, Argon, Neon or Xenon lamps, and Deuterium and Xenon arc lamps for radiometric calibration or absorption measurements.

**Fibre optic**
Multi-leg fibre ferrules “round-to-line” configurations, for maximum light collection along spectrograph entrance slit and multi-channels simultaneous acquisition with imaging-optimized spectral instruments.

More information at andor.com/learning

**Accessory Trees**
Please refer to p32

**Grating Selection**
Please refer to p33

**Fibre Optics**
Please refer to p34

**Microspectroscopy**
Please refer to p36
“Discover new ways of seeing™” takes its true meaning when the most sensitive spectroscopy detection solutions on the market combine with Andor’s comprehensive software capabilities. From seamless configuration of spectrographs and cameras to actual data acquisition optimization, Andor Solis software and Software Development Kit (SDK) offer a truly powerful, yet user-friendly modular approach to spectroscopy.

**Software Development Kit (SDK)**

Andor SDK features a comprehensive library of camera and spectrograph controls, ideally suited for complex experiments integration including third party hardware control and SDK – i.e. microscope motorized stage or light sources – and user specific data analysis protocols. Available as 32 and 64-bit libraries for Windows (XP, Vista and 7) and Linux, the SDK provides a suite of functions that allow configuration of the data acquisition process in a number of different ways. The dynamic link library can be used with a wide range of programming environments including C/C++, C#, Delphi, VB6, VB.NET, Labview and Matlab.

**Solis for Spectroscopy**

Modular Raman spectroscopy, Laser Induced Breakdown Spectroscopy (LIBS) and Plasma diagnostics are only a few examples of applications where Andor Solis Spectroscopy allows researchers to truly focus on their own experimental challenges. With its unique interactive real-time control interface, users can optimize system optical performance through wavelength, gratings and entrance/exit slits selection at the touch of a button, while accessing all key detectors acquisition parameters to optimize the quality of the signal. Solis also features a comprehensive range of acquisition options including ultrafast kinetic series and “Crop mode” operation, simultaneous multi-track recording, photon-counting mode, and time-resolved series capture for lifetime fluorescence studies.

**Solis Scanning**

With detection capabilities ranging from UV to the Long Wave IR (LWIR) region through a comprehensive range of single point detectors – including PMTs, PbS and MCT – Solis Scanning offers a dedicated platform for scanning applications. Spectrograph/monochromators, detectors, data acquisition unit, lock-in amplifier/chopper and motorized accessories can all be conveniently synchronised through a series of intuitive interfaces. A single software package features a comprehensive step-by-step experiment building interface for parametrising and synchronizing all components of the detection chain. Complex scanning sequences involving multiple gratings, filters and up to two monochromators for fluorescence measurements – including a tunable light source setup - can be seamlessly captured prior to acquisition start and executed without further intervention of the user. Solis Scanning can also handle multiple detectors control and data display for Absorption - Transmission - Reflection spectroscopy, while offering post-acquisition mathematical data processing ranging from simple ratios and lifetime measurements to fast phenomena analysis.

**μManager**

This third party software platform offers extensive control of microscope and microscope accessory devices as well as Andor’s Shamrock 193i spectrograph and spectroscopy cameras, allowing simple control of complex micro-spectroscopy experiments.

More information at andor.com/software
Access to an unlimited range of detection system configurations is the basis of Andor’s modular approach to spectroscopy. That is why Andor is continuously and dynamically expanding its range of field-upgradable accessories to meet the ever-growing demand from researchers. This now includes enhanced options for combining microscopy and spectroscopy.

Looking for light coupling interfaces to Andor spectrographs? Get an instant view of all standard accessories and follow the configuration trees to check for compatibility.

Can’t see exactly what you are looking for? Do you want a grating with a different groove density or a different blaze angle, FC connection instead of SMA or custom light coupling between microscope and spectograph? Andor’s experienced and dedicated Customer Special Request (CSR) team will be eager to discuss your specific needs.

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Specification sheets andor.com/spectroscopy
Resolution calculator andor.com/calculators
Fibre Optics Solutions

Fibre optic is one of the most convenient ways to collect and transport light from an experimental set-up to a spectrograph-based detection solution. Andor’s series of “round-to-line”, multi-core fibre optic bundles maximizes the signal collection by positioning the multiple cores alongside the spectrograph entrance slit. Andor works with industry leading manufacturers to deliver solutions to meet any user requirements.

<table>
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<th>Number of legs</th>
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</table>

a. Total fibre optic bundle height  b. Individual channel height (five fibres)  c. Spacing between individual channels (dead fibres)

Key Specifications

- UV-Vis and Vis-NIR optimized options
- Numerical Aperture = 0.22
- 100 and 200 μm fibre core options
- From 1 to 5 leg options as standard
- Standard SMA connectors to Ø 11 mm
- Andor ferrule
- 2 m overall length – setup convenience and minimum transmission losses
- Re-enforced shield and ruggedized connectors
- Compatible with Andor Shamrock
- F/number matchers and X-Y adjusters

Have you found what you are looking for?

Need a different fibre core size? A longer overall cable? FC connectors? Additional channels or legs?
Please contact your local Andor representative to discuss your specific needs.
Adding structural and chemical spectral analysis to Microscopy images of bio-samples such as cells and proteins, or materials such as polymers or semi-conductors, is an ever increasing demand amongst the research community. Andor’s range of modular interfaces feature cage systems couplers, allowing endlessly configurable connections between Andor Shamrock spectrographs and a wide range of market leading microscopes such as Nikon, Olympus, Leica and Zeiss. The Shamrock “wide-aperture” slit opens the door to a single setup with a single detector to image the sample, whilst allowing spectral information collection through the same optical path from the microscope.

### Key Applications

- Micro-Raman
- Micro-Fluorescence - Luminescence
- Micro-LIBS

### Modular approach to combined microscopy and spectroscopy

#### Features

- C-mount interfaces
- Microscope feet
- Wide-aperture slit
- Thorlabs or Linos cage systems compatible interfaces
- EMCCD compatible
- Software Development Kit

#### Benefits

- Seamless integration of Shamrock spectrograph-based systems to market leading upright and inverted microscopes
- Microscope left or right inverted output options – matches precisely Shamrock spectrograph optical height for accurate opto-mechanical coupling
- Up to 12 mm field of view - Andor’s imaging-optimized spectrographs allow high quality sample image relay, without compromise in spectral information collection through the same optical channel
- Fully user-configurable optical setups for Micro-Luminescence and Micro-Raman – compatible with 16, 30 and 60 mm systems
- Andor Newton and iXon platforms offer a unique combination of single photon sensitivity and high spectral rate and frame rate for challenging low-light spectroscopy
- Enables seamless integration with third party hardware and SDK under Labview, C/C++ and Visual Basic
Scanning Accessories

The perfect complement to Andor’s multi-channel detector portfolio

These accessories provide a perfect complement to Andor’s extensive range of market leading CCD, ICCD, InGaAs and EMCCD detectors. Shamrock spectrograph double detector output configurations allow detection from 180 nm to 12 μm with one single setup. Solis Scanning software platform provides a dedicated single interface for seamless parametering and synchronizing of single point detectors, spectrographs, data acquisition unit and lock-in amplifiers, with an intuitive interface for complex experiment acquisition sequences.

More information at andor.com/learning
Specification sheets andor.com/spectroscopy

**Recommended models include SRS SRI30 with associated SRI540 chopper**
Application notes and technical discussions – Andor in action

With over 50,000 users worldwide Andor products are represented in all the major universities, helping researchers to achieve key advances and discoveries by offering cutting-edge spectroscopy systems based on the latest technologies available. The result is a great breadth of exciting applications, collaborations and testimonials across researchers’ publications, which Andor is extremely proud to share with the scientific community.

Have you found what you are looking for?

Cannot see your publications referenced when your work involved Andor equipment? Are you interested to put forward some of your key innovations and results? Do you have spectacular images, movies or posters you would be keen to share? Are you interested in collaboration work around a particular application? Our team of application specialists will be eager to discuss your ideas.
Application Note

TERS – Label-free chemical analysis of nanostructures in biofilms

Tip-Enhanced Raman Spectroscopy (TERS) is developing into a powerful technique for the characterization of bio-molecules at the nanoscale level [1,2,3,4]. It facilitates chemical imaging on the scale of single molecules, extending well established techniques such as surface enhanced Raman Spectroscopy (SERS) and Raman mapping.

Work by Dr Thomas Schmid and co-workers from Prof. Renato Zenobi’s group at the Dept of Chemistry and Biosciences, ETH Zurich, demonstrates the use of TERS for label-free chemical characterization of nanostructures in biological specimens [1]. The biofilm system chosen for the investigation was based on calcium alginate fibres. TERS provides detailed chemical information at very high spatial resolutions (<50 nm), with one key advantage being label-free characterization. A TERS system essentially brings together scanning probe, microscopy and spectroscopy technologies.

Prof Zenobi’s group set out to test the feasibility of using TERS to carry out label-free chemical characterization of nanostructures within biofilms. Label-free techniques remove the challenges of labeling samples using dyes or tags. Calcium alginate fibres were considered a good representative model for the extracellular polysaccharides of biofilms.

A schematic of the setup used is shown in figure 1. It essentially consisted of three main subsystems – an Atomic Force Microscope - AFM (Veeco Instruments), an inverted confocal laser scanning microscope - CLSM (Fluoview, Olympus), and a Raman spectroscopy system consisting of a Holospec F/1.8i spectrograph (Kaiser Optical Systems) and an iDus 420 CCD camera (Andor Technology). The excitation laser (532 nm) was delivered via a single mode fibre. The CLSM unit delivered the light into the microscope, where it was focused onto the sample with an oil immersion objective (60x and NA=1.4). The scattered Raman signal was collected by the same microscope objective and passed back through the CLSM unit and a beam splitter to be focused into a multimode fibre, which delivered the signal to the entrance port of the spectrograph. An edge filter placed in front of the spectrograph was used to reject the Rayleigh scattered light from entering the spectrograph. The sample could be scanned in 2D directions. An AFM image is on the left and background corrected TERS spectra on the right. The latter were produced when the tip was a few nanometers from the surface (near-field). In contrast, when the tip was the order of microns from the surface (far-field), it had no effect and no spectral signature was evident even with very long exposures (10 mins). Schmid and coworkers identified characteristic marker bands for the macromolecules studied. They observed shifts in the Raman band positions for these complex macromolecules, in contrast to observations for the corresponding bulk samples of the same material which showed no shifts. It also contrasts with less complex molecules where there was no observed shift in the bands for the TERS spectra. They attributed the shifting in large part to the influence of chemical enhancement (CE) processes occurring at the tip interface.

In the first application of TERS on alginate fibres, the group successfully demonstrated the collection of weak Raman spectra at high spatial resolutions from extracellular polymeric substances (EPS) without the need for labeling. Such materials include polysaccharides, nucleic acids and proteins. This work represents a significant step forward in the development of the TERS technique as a reliable, accessible, and robust analytic technique for many applications in the life science, medical and materials fields.

Low photon signals place increased demands on the sensitivity of the detector used and the collection efficiency of the optical system. Only high performance cameras can give the required signal to noise ratios to make such measurements possible. The ideal system will be capable of single photon detection – an area where Electron Multiplying (EM) technology is of a definite benefit. High sensitivity facilitates the use of lower excitation fluences; this minimizes thermal effects and damage to the sample. Generally one is operating in a low light regime when collecting TERS spectra from a sample consisting of a few molecules. By carefully coating the silicon tip with silver, significant enhancements in the Raman signal are possible; typical enhancements of ~104 can be achieved. This enhancement is attributed to two main mechanisms:

- the excitation of surface plasmon modes between the tip and sample resulting in a multifold increase in the electric field intensity localized at the tip
- chemical enhancement due to the Charge Transfer (CT) mechanism when the molecules’ functional groups are in direct contact with the metal tip

Illustrative data is shown in figure 2. An AFM image is on the left and background corrected TERS spectra on the right. The latter were produced when the tip was a few nanometers from the surface (near-field). In contrast, when the tip was the order of microns from the surface (far-field), it had no effect and no spectral signature was evident even with very long exposures (10 mins). Schmid and coworkers identified characteristic marker bands for the macromolecules studied. They observed shifts in the Raman band positions for these complex macromolecules, in contrast to observations for the corresponding bulk samples of the same material which showed no shifts. It also contrasts with less complex molecules where there was no observed shift in the bands for the TERS spectra. They attributed the shifting in large part to the influence of chemical enhancement (CE) processes occurring at the tip interface.

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Stand-off techniques have received increasing attention as valuable methods for material analysis at remote distances. This is particularly relevant when looking at hazardous contaminants in the environment or residual explosive material, where it is desirable for the analyst to remain at a safe distance from the material being investigated.

Work carried out by Prof JJ Laserna's group at the Dept of Analytical Chemistry in the University of Malaga, reported by González et al.[1], explores the use of stand-off Laser Induced Breakdown Spectroscopy (stand-off LIBS) for the detection of explosive residues in situations simulating ’real environment’ scenarios. They looked at the feasibility of detecting the likes of improvised explosive materials (IEM) through windows such as those in cars or buildings or within various types of container. A telescopic system was used to focus a high power pulsed laser to a spot on the material to produce a micro-plasma. The same telescope collected the light emission from this plasma which was then analyzed in a spectrograph using the advanced time-gating of an intensified CCD camera.

The ability to detect dangerous contaminants, improvised explosives (IED), home made explosives (HME), or nuclear by-products, has become of increasing importance due to heightened risks in recent decades. In their work, Gonzalez and co-workers set out to test the feasibility of making such measurements with their TELELIBS sensor, and to assess the influences that the barrier position and its composition might have on the quality of those measurements. In allied work the group looked at the influence of atmospheric turbulence. In this work a delay of 400 ns was used along with an exposure or integration time of 9 μs.

Among the substances investigated were sodium chlorate (NaClO3), dinitrotoluene (DNT), trinitrotoluene (TNT), and some plastic explosives (C2 and H15). A number of barrier materials, including clear glass, some tinted glasses, and colorless PMMA (a polymer material) were placed in the beam path. The team investigated the influence of the target-to-barrier distance on the measured signal to background (S/N) ratio, along with the influence of the optical characteristics of the barrier material, thus accounting for the transmittance of excitation laser light and the returning plasma emission. A suite of chemometric tools were used to analyze the spectral data for the presence or absence of explosive residues.

A number of spectral bands and atomic/ionic emission lines were chosen for fingerprinting and subsequent identification of the explosive substances: examples of such features included the CN band (388.3 nm), the C2 band (471.5 nm, 516.5 nm and 563.5 nm), and the Al (I) line (469.4 nm) among others. The ability to detect a residue wasn’t determined by the ‘sensitivity’ and ‘specificity’ of the measuring system. Sensitivity is related to the system’s ability to identify the presence of an explosive material if it is present i.e. the system flags up the presence of the material when it should. Specificity is related to its ability to identify explosives only if they are present i.e. the system doesn’t flag up the presence of explosive when it shouldn’t. González and co-workers assessed the capability of their system by measuring the sensitivity for the different residues with the different barrier materials. By increasing the number of laser shots it was possible to increase the detection to 100% sensitivity without impacting on specificity.

Gonzalez and co-workers successfully demonstrated the feasibility of using the stand-off or TELELIBS technique for detection of explosive materials through different types of window or interposed barriers, as long as there was a clear line of sight from the sensor system to the target. They also demonstrated that relatively few laser shots were required to ensure a high level of detection capability and means of distinguishing different residues and that the position of the barrier relative to the target and sensor was unimportant to the analysis. A key enabler for this type of work is the high sensitivity and gating versatility offered by the Star ICCD camera. Research and validation on stand-off analysis techniques has gained much momentum as demands grow for safe, convenient and quick ways of testing for improvised explosives devices and other hazardous contaminants in the environment.

More recently the group have demonstrated the simultaneous use of both stand-off LIBS/stand-off Raman to analyse such materials.[4]

Acknowledgement: Appreciation is gratefully extended to Prof JJ Laserna and his group, University of Malaga, Spain.

Reference material:
Application Note

Development of a Raman detector for hyphenation with high-temperature liquid chromatography and isotope ratio mass spectrometry

According to criminal statistics, product and trademark piracy have increased dramatically in recent years. The critical numbers of fake articles in foodstuffs, pharmacy and cosmetics exhibit potential risks for public health. Product counterfeiting can be identified by determining the origin and authenticity of the chemical compounds that are part of fake articles.

After applying a separation by high-temperature high performance liquid chromatography (HT-HPLC) origin and authenticity of analytes are revealable by isotope ratio mass spectrometry (IRMS). The sole linkage of HT-HPLC and IRMS can be used if the composition of samples is known. The analysis of samples with unknown composition additionally requires the identification of the separated compounds. A detection system based on Raman spectroscopy was specifically developed for this experimental approach. The principle of measurement is shown in Figure 1:

Raman signals were generated within the liquid core waveguide. The Raman light was collected by optical fibre 2 that directed the scattered light to the spectrograph and CCD detector (HoloSpec f/1.8i from Kaiser Optical Systems and Newton D920P-BV CCD from ANDOR Technology, Figure 3) for the spectral detection.

The experimental setup including hyphenation of HT-HPLC, Raman detector and IRMS is shown in Figure 2. The Raman device was inserted between HT-HPLC and IRMS and operated like a flow cell for online detection. The laser light was guided by the optical fibre 1 to the T-piece 1 which coupled the HT-HPLC capillary tubing, the liquid core waveguide and the optical fibre 1.

A picture of the flow cell device and the liquid core waveguide during Raman measurement is shown in Figure 4.

Figure 4: Flow cell device during Raman measurement, excitation wavelength: 532nm, 1: Liquid core waveguide with ID=250µm, length=1m, 2: Optical fibre 1, 3: T-piece 1, 4: Optical fibre 2, 5: Capillary tubing from HT-HPLC, 7: Capillary tubing to IRMS.

Results

The applicability of the described setup was tested with a mixture of sulfathiazole and sulfamerazine. The analytes were solved in a 50:50 mixture of water and methanol with a concentration of 100 mg·L⁻¹ for each substance. The injection volume on column was 20 µL. A laser power of 2 W and a detection time of 10 s were used to capture the Raman spectra shown in Figure 5.

Conclusion

Raman spectroscopy is a promising on-line detection technique for the hyphenation of high-temperature liquid chromatography with isotope ratio mass spectrometry. Analytes can be unambiguously identified by their characteristic Raman spectra. Based on the Raman scattering cross section of the analyzed substance, a limit of detection of 1 - 4 mg·L⁻¹ (< 10⁻⁵ M) was successfully achieved.

Acknowledgement

This work is part of a close cooperation with the Institute of Energy and Environmental Technology e.V., IUTA (working group of Dr. T. Teutenberg) and the University Duisburg-Essen, Instrumental Analytical Chemistry (working group of Prof. Dr. T.C. Schmidt). The authors would like to thank the German Federal Ministry of Economics and Technology for their financial support, part of the industrial cooperative research and development (IGF) programme, initiated by the German parliament. The access was opened by the Verein zur Förderung der Energie - und Umwelttechnik e.V., VEU, Duisburg and organised by the AIF, Arbeitsgemeinschaft industrieller Forschungsvereinigungen e.V., Köln. (IGF-Projekt No. 16120 N/2).

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Fischer, B., Entwicklung eines empfindlichen Raman-Detektors für die Flüssigchromatographie, ANAKON 2013, Essen (Germany), Mar 4-7 (2013).
Magneto-PL unveils photoluminescence in Si nanocrystals

Silicon (Si) as a material has dominated the field of microelectronics for quite some time, but when it comes to photonic devices it has had little impact due to its poor light emitting properties. However, nano-structured Si shows a marked increase in light emission efficiency; this was initially observed in porous Si, and more recently in Si nanocrystals.

Explanation of the source of this light emission has been strongly debated over the last two decades, with two possible sources being suggested – a) the influence of localized structural defects and b) the effects of Quantum Confinement (QC) within the nanostructure. Work reported by Dr Manus Hayne and co-workers in Nature Nanotechnology [1, 2], has given much insight into the underlying mechanisms. Using an elegant technique based around magneto-photoluminescence (magneto-PL), they were able to distinguish between the two mechanisms by a cycle of measurements on crystallized and amorphous samples. This was followed by passivation of defects with hydrogen, and the subsequent reintroduction of defects by removal of the hydrogen. A key enabler to their work was the ability to measure the very weak PL signals using the high sensitivity detection capability offered by Electron Multiplication (EM) technology.

The quest for silicon-based photonic devices continues unabated with the ultimate goal of seamless integration of photonic devices, such as sensors or light emitters, and the associated digital data-processing electronics. Currently most photonic devices are based on III-V and II-VI semiconductors, whilst all digital electronics are silicon based. This leads to challenges and limitations when it comes to the integration of the different technologies in one system. One example is the use of optical interconnects from chip-to-chip and board-to-board in electronic systems. The emission of light from silicon nanocrystals has given hope to the developments of fully integrated systems based on one material technology. Hayne and co-workers at Lancaster University, Albert Ludwigs University in Freiburg, the Katholieke Universiteit Leuven, and the University of Antwerp set out to understand the fundamental mechanisms underlying this light emission.

A schematic of the experimental set up used by the team is shown in figure 1. The samples consisted of Si nanocrystals – typical diameter of ~3 nm – embedded in SiOx, formed by annealing of SiOx/SiO2 layers on Si substrates. Characterization was carried out using high resolution TEM (HR-TEM) imaging, electron spin resonance (ESR) analysis and magneto-PL. PL spectra consisted of broad Gaussian lines, with line width is 300 meV (Courtesy Dr M Hayne, Lancaster University).

In their magneto-PL technique, the application of a high magnetic field is used to manipulate the confinement effects on the free carriers within the nanocrystal [3]. As a consequence of this field-induced ‘squeezing’ of the electrons, a characteristic shift in the wavelength of the light emitted from quantum confinement states should be observed; the higher the field, the higher the PL energy. However, electrons associated with highly localized defects with a characteristic confinement <1 nm should be unaffected by the magnetic field; the light emitted from these sources is expected to exhibit no shift in PL energy. Hence the method has the ability to distinguish between those states confined to a few nanometers and those associated with defects.

The first set of magneto-PL measurements were carried out on an as-crystallized sample; the PL emission was observed to be insensitive to the application of the magnetic field. The sample was then passivated in pure hydrogen at 400°C, which served to de-activate the defect sites. The emission from the passivated sample was then observed to give the expected shift in the emission wavelength with variation in the magnetic field strength, there was a shift of ~1.5 meV with the application of a 50 T field. This is illustrated in figure 2. We also observed that the overall intensity of the emission increased. A characteristic parabolic shift was observed (figure 2) with field increase, consistent with a wavefunction extent of ~5 nm. This confirmed that the emission was dominated by QC effects in this case. The researchers then went on to reactivate the defects by exposing the sample to intense UV illumination, which removed the ‘passivating’ hydrogen from the defect sites. The PL data again reverted back to show sensitivity to the application of the magnetic field, indicative that the emission was again dominated by it due to the localized defects. The results confirmed that when present, defects are the origin of the bulk of the emission within Si nanocrystals, and when there are no defects the emission is dominated by quantum confinement effects within the nanostructure.

EM technology as implemented on the iXon3, successfully met the major challenges posed by such an experiment, namely the sensitivity to measure extremely weak PL signals, and the speed to allow for averaging over a large number of spectral acquisitions.

Acknowledgement: Graphs courtesy of Dr Manus Hayne, Lancaster University, England.

Reference material:

Figure 1: Schematic of experimental set-up at Katholieke Universiteit Leuven, Belgium. The samples were mounted in a cryostat (middle) where they were cooled to 85K. High magnetic fields were applied across the samples as illustrated in the typical characteristic (lower right). The acquisition of the PL signal was timed to coincide with the peak of the applied magnetic field illustrated by the grey bar. The excitation laser was delivered through an optical fibre (top left) and the resultant PL signal was fed via collection fibres into a remotely located Shamrock spectrograph with iXon3 detector.

Figure 2: Shift of the photoluminescence (PL) energy for the passivated sample in which there is quantum confinement. The inset shows typical spectrum before (as-crystallized) and after passivation. Note that the PL shift with field is only ~1.5 meV and the line width is 300 meV (Courtesy Dr M Hayne, Lancaster University).
Technical Note

Low Dark Current Deep-Depletion (LDC-DD) Technology
A new standard for low-light NIR spectroscopy

Standard back-illuminated, deep-depletion (BI-DD) CCDs offer quantum efficiencies (QE) up to 95% in the near-infrared (NIR). This makes them the detector of choice for photoluminescence, Raman or plasmonics spectroscopy in the 700 - 1,100 nm range. One disadvantage of deep-depletion devices has been a significant associated increase in dark current (~100 times) compared to standard back-illuminated, visible-optimized CCDs. A new generation of Low Dark-Current, Deep-Depletion (LDC-DD) CCDs now overcomes this limitation, and challenges the need for liquid-nitrogen (LN$_2$) cooling for photon-starved NIR spectroscopy.

Introduction

Dark current is a source of noise inherent to CCDs. It arises from thermally generated charges in the silicon lattice over time. Cooling is the most efficient means of reducing dark current in CCDs, and there are a number of methods (incl. combinations) traditionally used, such as air, liquid coolant, liquid nitrogen (LN$_2$) and thermoelectric (TE). A new generation of back-illuminated, deep-depletion CCDs (LDC-DD) now offers excellent dark-current characteristics whilst offering >95% QE in the NIR. This technical note analyses the benefits of this technology by considering the influence of temperature on quantum efficiency (QE) and dark current. It also aims to show that ‘cooler is not necessarily better’, and that the combination of LDC-DD and TE-cooling obsolesces the need for LN$_2$ cooling technology for BI-DD CCDs.

Back-illuminated, deep-depletion (BI-DD) – the attraction of high NIR QE

The QE of a CCD is governed by its ability to absorb incoming photons in the photosensitive silicon region. It is only in this region that photons are converted into electron-hole pairs, which are then confined by means of electric fields into a ‘pixel’. The charges held in those pixels can then be transferred and detected. Shorter wavelength photons (blue light) are absorbed close to the silicon surface, while longer wavelengths photons can travel deeper into the silicon matrix before being absorbed. Photons above 1.1 μm do not have enough energy to create a free electron-hole pair that could be detected: a silicon CCD is effectively transparent at these longer wavelengths.

Fig. 1 shows the absorption depth of photons as a function of incident photon wavelength.[1] In order to eliminate the losses incurred at the front surface, a back-illuminated (BI, Back-thinned) configuration can be adopted. When a device is back-thinned, the bulk substrate is removed by mechanical grinding and chemical etching so that light can enter from the back surface directly into the active photosensitive region. These devices can exhibit peak QE of up to 95% with appropriate anti-reflection (AR) coatings.

In front-illuminated CCDs, incoming photons must first transverse a polysilicon electrode structure and a silicon oxide (SiO) insulating layer (see Fig. 2). The electrode structure can absorb and reflect longer wavelength photons, and subsequently lowers the probability for these photons transversing the whole way across the active region (refer to Fig. 1).

These devices are known as back-illuminated, deep-depletion (BI-DD) CCDs.

NIR QE of standard back-illuminated CCDs can be further enhanced by the use of a thicker photosensitive region (typ. 30-50 μm) and higher resistivity material. The thicker photosensitive region offers a greater absorption path to longer wavelength photons, and subsequently lowers the probability for these photons transversing the whole way across the active region (refer to Fig. 1).

The higher resistivity material allows the electric fields, created by applying voltages to the electrodes, to penetrate the entire depth of the now thicker photosensitive region and hence better collect and confine photoelectrons within the pixels. These devices are known as back-illuminated, deep-depletion (BI-DD) CCDs.

Influence of CCD cooling on QE

The absorption depth of photons in the silicon can increase with cooling[3]. This is especially pronounced in the near-infrared, and effectively means that the CCD becomes increasingly transparent to NIR photons. This lower probability of absorbing a NIR photon translates into a decrease in QE (see Fig. 5).

BI-DD CCDs present the best QE in the 750 – 1,100 nm region, up to 95%, but this also means that they are the most prone to QE variation with cooling temperature. This is a consequence of band-gap shifting. At an illustrative wavelength of 950 nm, the probability of an incoming photon generating a detectable photoelectron in the photosensitive layer of a CCD can drop by up to 50%.

These devices have the following QE performance at +25ºC:

- **Front-illuminated (BI2)**: 51.5% QE
- **Back-illuminated, NIR-optimized AR coating (BI-DD)**: 56.5% QE
- **Back-illuminated, deep-depletion CCD with NIR-optimized AR coating (BI-DD)**: 62% QE

For a typical LDC-DD device, the QE at +25ºC will be approximately 70%.

In order to better understand the limitation in dark current for current deep depleted devices it is first necessary to understand some concepts regarding CCD structure and how these influence dark current behaviour.

Scientific CCDs are usually manufactured on epitaxial silicon with a thickness of the order of ~15 μm. A typical CCD is made up of pixels which are defined by the permanent channel stops in one direction and by the image phases in the perpendicular direction. (see Fig. 6).

Data supplied by sensor manufacturer[2]

Since a CCD must first collect the incoming photons before detecting the associated photo-electron(s) generated in the active silicon region of the sensor, any decrease in QE must therefore be weighed against the actual dark current improvement benefit for a given experimental scenario.

The following section will focus on the impact of cooling on dark current alone for both standard BI-DD and the new BI LDC-DD technology. The effect on signal-to-noise performance – combining the influence of both QE and dark current variation influence - will be examined subsequently.

Dark current in back-illuminated, deep-depletion CCDs: ‘NIMO’ vs ‘IIMO’ design

In order to further understand the limitation dark current for a CCD in deep depleted devices, it is first necessary to understand some concepts regarding CCD structure and how these influence dark current behaviour.

Scientific CCDs are usually manufactured on epitaxial silicon with a thickness of the order of ~15 μm. A typical CCD is made up of pixels which are defined by the permanent channel stops in one direction and by the image phases in the perpendicular direction. (see Fig. 6).

Charge clocking direction (towards readout register)

Figure 1: Absorption depth in Silicon at 300K as a function of incident photon wavelength[1]

Figure 2: Typical front-illuminated CCD (cross section)

Figure 3: Typical back-illuminated CCD (cross section)

Figure 4: Typical QE performance at +25ºC of front-illuminated (BI), back-illuminated visible-optimized (BI-2), UV-enhanced silicon back-illuminated (BI2U2) and back-illuminated deep-depletion CCDs with NIR AR-coating (BI-DD) and broadband dual AR-coating (BI2ED2). The new BI ‘LDC-DD’ and ‘BR-DD’ have identical QE characteristics.

Figure 5: Typical QE variation with cooling temperature of back-illuminated, deep-depletion CCD with NIR-optimized AR coating. Data supplied by sensor manufacturer[2]

Figure 6: Pixel architecture of a buried channel 3-phase
The image phases are electrode gates that run across the outer surface with the photosensitive region below. Applying a voltage to an electrode gate depletes the region below of electrons producing a potential well, often referred to as the ‘depletion region’. It also causes any charge to gather under the nearest most positive (in voltage) phase and by controlling when this voltage is applied, we can define individual pixels and transfer them, on mass, across the CCD area and into the readout register.

**Non-inverted mode operation (NIMO) CCDs**

At all times at least one of the gate electrodes must be low while the other(s) are high, even during transfer. This is to ensure that charge in one pixel is not mixed with charge from its neighbouring pixels. Electronically this is not a problem to arrange, and is generally referred to as ‘clocking’. This configuration is referred to as Non-Inverted Mode Operation (NIMO) (see Fig. 7).

However it turns out that about 100 times more dark current is generated when any image clock is held high compared to low. This can lead to a substantial build-up of dark signal during long integrations.

**Inverted mode operation (IMO) CCDs**

By keeping the clock level sufficiently low, holes from the channel stop can be attracted into this interface and ‘neutralize’ the electron sources. When this state is reached it is referred to as ‘pinning’. Further lowering of the phase potential will have no effect inside the silicon simply because more holes arrive to pin the voltage, hence the name.

**Low Dark-Current Deep-depletion (LDC-DD) Technology**

Fig. 9 shows the dark current characteristics versus cooling temperature of a standard back-illuminated, deep-depleted CCD (dotted orange line) and the new iDus 416 LDC-DD CCD (red line).

At an equivalent pixel size of 15 μm, the LDC-DD shows a significant 10 times dark current performance improvement when compared to a standard deep-depletion CCD.

The disadvantage of the elevated dark current on standard deep-depleted devices has meant a compromise has to be made: either improved NIR QE response and higher dark current; or lower QE and low dark current.

The reason for this higher dark current has been the inability to ‘pin’ a deep-depleted CCD. To date neither IMO nor AIMO have been available in conjunction with deep-depletion, since inverting (or pinning) the surface during integration reduces the voltage available. This therefore restricts depletions, limiting the advantage of a high resistivity substrate.

However we at Andor have partnered with E2V in order to overcome this restriction, and bring the groundbreaking back-illuminated LDC-DD technology to the Academic and Industrial world to greatly facilitate photon-starved spectroscopy acquisition in the NIR. This virtually obsoletes the very inconvenient and unpractical LN cooling approach (compared to maintenance-free thermo-electric (TE) cooling).

**LDC-DD technology - achieving high signal-to-noise for much shorter exposures**

The following scenarios look at a SNR performance in the context of spectroscopy, where the signal is vertically binned in a number of rows on the CCD. The impact of the lower dark current of the LDC-DD technology on SNR is shown in Fig. 10.

**Signal-to-noise (S/N) – true basis for detector sensitivity assessment**

Signal-to-noise is an essential tool for assessing the combined effect of QE and noise variation in CCDs. It is the achievable signal-to-noise, which is of key importance when assessing the performance of any detector in terms of its sensitivity. For CCDs, it can be defined as follow:

\[
S/N = \sqrt{\frac{S^2}{N_{NRN}^2 + N_{NDN}^2 + N_{SN}^2}}
\]

Where S is the photon signal, NRN the readout noise, NDN the dark current noise, NDC the spurious charge noise at clocking-induced discharge and NSN the incoming signal shot noise. It can also be expressed as:

\[
S/N = \frac{QE.I.t}{\sqrt{N_{NRN}^2 + DC.t + N_{CR}^2 + QE.I.t}}
\]

Where QE refers to the sensor quantum efficiency (%), I the incoming photon flux (photons/s), t the exposure time (s) and DC the dark current (e-/pix/s or e-/CCD column/s).

Since CCD cooling impacts both dark current and sensor QE, one must consider the following:

1. Is there some temperature point in cooling beyond which further cooling may be detrimental to the overall performance in terms of S/N, i.e. is there a point where the reduction in QE is more influential than further reduction in the dark current?
2. What is the trade-off between the influences of the reduction in QE and the reduction in dark current, with cooling for a given sensor?
Both technologies can achieve good SNR performance. However, the back-illuminated LDC-DD provides equivalent SNR at much shorter CCD exposure times.

In the scenario above, the back-illuminated LDC-DD CCD will achieve a good SNR of 10 with an exposure time of nearly two minutes shorter. For a SNR of 25, this difference is ~15 minutes.

TE-cooling and LDC-DD technology: achieving the best performance without the inconvenience of LN$_2$

Liquid nitrogen-cooled CCDs typically operate at -120°C, and have been considered as the standard for photon-starved NIR spectroscopy applications for decades.

Modern TE-cooled CCDs can achieve -100°C, while offering great advantages:

- Maintenance-free operation - no need for regular LN$_2$ refilling and associated safety concerns - ideal for 24/7 industrial applications
- Transportability - ideal for integration into modular instrumentation
- Lasting performance – sensor sits in vacuum and is protected from any degradation that could result in loss of QE
- Low cost

Fig. 11 shows a very challenging photon regime, and compares the SNR performance of an LN$_2$-cooled BI-DD CCD at -120°C with a back-illuminated LDC-DD CCD TE-cooled to -95°C.

In this extreme light level scenario, SNR performance between the two technologies is identical for exposure times greater than ~30 s. At shorter exposure times, the difference in SNR at a given exposure time is less than 10%, which is minimal.

At higher photon flux, the trend is even more pronounced, with an even closer match at the shortest exposure times.

Conclusion

In conclusion, with the combination of -95°C TE cooling and back-illuminated LDC-DD technology, the highest detection performance in the NIR can be achieved even at an extremely challenging photon flux. At higher photon flux, this technology combination will exceed the performance of standard -120°C, LN$_2$-cooled back-illuminated BI-DD CCDs. So when looking for the best NIR sensitivity and the most convenient cooling means, Andor’s iDus 416-95°C TE-cooled platform with back-illuminated LDC-DD CCD technology has no equivalent.

LDC-DD optical etaloning

Optical etaloning is an important point to be mindful of when working with back-illuminated CCDs in the NIR. The back-illuminated LDC-DD CCD benefits from a fringe-suppression process implemented during sensor manufacturing, which helps to ‘break’ the Fabry-Pérot étalon formed by the reflections in the CCD depletion region. The maximum peak-to-peak fringing modulation typically varies from 1-5%: these variations are inherent to the manufacturing process at CCD batch level. Refer to Andor technical note “Optical Etaloning in Charge Coupled Devices (CCDs)” for further details on optical fringeing in CCDs.

Appendix B

Estimates for cost/time analysis with Liquid N$_2$ cooling.

N$_2$ cooling does involve added overheads in terms of raw material and handling costs, as well as the inconvenience with handling and associated health and safety considerations. Outlined here is a simple estimate of the costs for supply of LN$_2$ to cool the CCD camera over a period of five years.

<table>
<thead>
<tr>
<th>Description</th>
<th>Wavelength range (nm)</th>
<th>Peak QE</th>
<th>Fringe suppression process</th>
<th>Peak modulation amplitude</th>
<th>Dark current</th>
<th>Andor platform</th>
</tr>
</thead>
<tbody>
<tr>
<td>FI</td>
<td>400 - 1,000</td>
<td>58% @ 770 nm</td>
<td>Not necessary</td>
<td>0%</td>
<td>Very low</td>
<td>iDus 421, Newton 940, NewtonEM 970, NewtonEM 971</td>
</tr>
<tr>
<td>OE</td>
<td>Open electrode</td>
<td>&gt;200 - 1,100</td>
<td>58% @ 770 nm</td>
<td>Not necessary</td>
<td>0%</td>
<td>Very low</td>
</tr>
<tr>
<td>BIV</td>
<td>Back-illuminated, Visible-optimised AR coating</td>
<td>&gt;200 - 1,100</td>
<td>97% @ 550 nm</td>
<td>No</td>
<td>20-40% (850 - 900 nm)</td>
<td>Low</td>
</tr>
<tr>
<td>BIVF</td>
<td>Back-illuminated, Visible-optimised AR coating</td>
<td>&gt;200 - 1,100</td>
<td>97% @ 550 nm</td>
<td>Yes</td>
<td>10-20% (850 - 900 nm)</td>
<td>Low</td>
</tr>
<tr>
<td>BR-DO</td>
<td>Back-illuminated, Deep-depletion 749-nm-optimised AR coating</td>
<td>&gt;200 - 1,100</td>
<td>95% @ 800 nm</td>
<td>Yes</td>
<td>1.5-5% (950 nm)</td>
<td>High</td>
</tr>
<tr>
<td>BRDO-DO</td>
<td>Back-illuminated, Deep-depletion 749-nm-optimised AR coating</td>
<td>&gt;200 - 1,100</td>
<td>95% @ 800 nm</td>
<td>Yes</td>
<td>1.5-5% (950 nm)</td>
<td>High</td>
</tr>
<tr>
<td>LDC-DD</td>
<td>Back-illuminated, Deep-depletion 749-nm-optimised AR coating</td>
<td>&gt;200 - 1,100</td>
<td>95% @ 800 nm</td>
<td>Yes</td>
<td>1.5-5% (950 nm)</td>
<td>Low</td>
</tr>
</tbody>
</table>

Appendix A

Key spectroscopy sensor flavours and platforms by Andor Technology

Andor’s iDus 416A-LDC-DD also offers:

- 2000 x 256 array - 30 mm wide sensor for extended band-pass capture
- 15 μm pixels for high resolution spectroscopy
- -95°C Thermo-Electric cooling – maintenance-free
- Ultravac™ vacuum technology for lasting superb detection performance

References

Customer Support

Andor products are regularly used in critical applications and we can provide a variety of customer support services to maximise the return on your investment and ensure that your product continues to operate at its optimum performance.

Andor has customer support teams located across North America, Asia and Europe, allowing us to provide local technical assistance and advice. Requests for support can be made at any time by contacting our technical support team at andor.com/support.

Andor offers a variety of support under the following format:

- On-site product specialists can assist you with the installation and commissioning of your chosen product
- Training services can be provided on-site or remotely via the Internet
- A testing service to confirm the integrity and optimize the performance of existing equipment in the field is also available on request.

A range of extended warranty packages are available for Andor products giving you the flexibility to choose one appropriate for your needs. These warranties allow you to obtain additional levels of service and include both on-site and remote support options, and may be purchased on a multi-year basis allowing users to fix their support costs over the operating life cycle of the products.