Review of Solid State Photon Counters for Laser Ranging to Orbital Space Debris

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OUTLINE

- Requirements on detectors
- Detectors available - review
  - Si SPAD detectors (VIS)
  - Ge and InGaAs SPAD detectors (NIR)
  - Superconducting detectors (NIR)
- Conclusion
Requirements put on detectors for space debris laser ranging

- EXPERIMENT ENERGY BUDGET
  = > single photon response
  high Photon Detection Efficiency (PDE)

- LASER SOURCES AVAILABLE & SAFETY
  = > sensitive @ 532 or 1064 or 1550 nm

- OPTICAL TRACKING TELESCOPE FoV
  = > detector aperture >= (50) 100 um

- FIELD OPERATION
  = > robust, reliable
Photon counting detectors
key parameters for laser ranging

- **VACUUM / PHOTOCATHODE** based
  - Apertures: 1 mm .. 1 meter
  - Wavelength range: UV .... 1550 nm
  - Photon Detect. Eff.: 30 % .... 0.1 %

- **SEMICONDUCTING** detectors
  - Apertures: 0.1 ... 0.5 mm
  - Wavelength:
    - 532 ... 1064 nm Si
    - 532 ... 1550 nm Ge / 77K
    - 1064 ... 1550 nm InGaAs
  - PDE: 70 % @ 532 nm Si

- **SUPERCONDUCTING** detectors (kryo-cooled)
  - Apertures max.: 10 um (50 um ?)
  - Wavelength: UV .... 1550 nm
  - PDE: > 70 % @ 1550 nm

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Si SPAD Detector Package for SLR
jointly Czech Tech. Univ. in Prague and IWF Graz

- Self-consistent compact package
- SPAD TE cooled in vacuum
- collecting optics f/D = 1.0
- time walk compensation
- 50 x 50 x 130 mm, 300 g

- Detector aperture 200 um, f/D = 1, => acceptable FoV
- Photon Det. Efficiency ~ 40 % @ 532 nm (P.Guilemont, CNES, 2006)
- Used by > 15 SLR stations worldwide
- Applied for the first space debris laser tracking demonstration

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SPAD detector package for SLR applied for space debris laser tracking

Mt. Stromlo, Australia, 2002
www.eos-aus.com/space/education/..

Shanghai, China, July 17, 2008
discarded US rocket (ID 2007-006G)

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SPAD detector package with high PDE for space debris tracking

- High Photon Detection Efficiency PDE
- SAP500 detector by Laser Components
- APD on Si, 0.5 mm diameter, ~100 V break.
- PDE typically 70% @ 532 nm (M.Stipcevic, 2011)
SPAD detector package with high PDE #2
for space debris tracking, version 2015

- HQE Detector package developed
- Single TE cooling to -8°C
- 1:1 replaceable to other SPAD detectors
- Operational Graz, Wettzell, Shanghai,…

< 25 kHz @ 15V ab

220 ps @ 15V ab


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InGaAs/InP Photon Detectors 1064 nm

- candidate for 1064 nm operation in a near future
- "never ending story 1064 <-> 532 nm"
- gain of 1064 nm
  - 1 photon 2 x
  - SHG generation 2 x
  - atmo. atten. 1.5 x ?
  - Target reflect. ... ?
  - ----------------------------------
  - Total gain 4..6 x

- Detection efficiency >~ 15 % @ 1064 nm
- Active area 60 um diameter max.
- Dark count rate < 25 kHz / - 60 C
- InGaAs technology still in progress

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Germanium SPAD Detector Package for VIS - 1550 nm

- Ge SPAD, 100 um / 77 K
- PDE ~ 20% @ 400..1064 nm
  2 - 5% @ 1540 nm
- dark count >= 1 MHz
- SLR and space debris LR @ 1540 nm demonstrated: CRL Tokyo, EOS Australia


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Superconducting Nanowire Single Photon Detectors

- High PDE: >70% 1550 nm
- Jitter: < 16 ps
- Dark count rate: < 100 Hz
- Temperature: < 4 K
- Size: “large” 25 um promised 50 um (?)

Proposal for a joint experiments by manufacturer

Application possibility depends on size and optical coupling improvements
Conclusion

- Photon counting is the only receiver option for laser ranging to orbiting space debris.

- SPADs on Si provide good detection efficiency at 532 nm, existing, available, heritage

- SPADs on InGaAs are promising candidates for 1064 nm range, energy budget if available

- Superconducting detectors are a dream for future systems operating at 1540 nm, energy budget, eye safety IF AVAILABLE

- Good News - Europe is a leader in developing these detectors We have good contacts to detector labs

- We should not miss this chance!

- Thanks for your attention

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Single Quantum
superconducting nanowire single photon detectors

Bias current $I < I_c$

Superconductivity recovered

Resistive barrier

Hotspot: High current density

Enlarged hotspot

Just a single photon can create a large enough hot spot in a 100 nm wide nanowire to stop the current flowing in the device. The meander geometry enables to cover a large surface area with a single nanowire.

Single Quantum BV, Lorentzweg 1, 2628CJ Delft, Netherlands
Single Quantum
superconducting nanowire single photon detectors

- Sensitive from UV to MIR
- Q.E. can be tailored for desired wavelength:
  - e.g. 80% Q.E. for 532 nm possible

![Graph showing detection efficiency vs wavelength](image)

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Single Quantum BV, Lorentzweg 1, 2628CJ Delft, Netherlands
Single Quantum
superconducting nanowire single photon detectors

- **High efficiency for NIR:** >75% for 1310nm, >70% 1550nm

![Graph showing detection efficiency and dark counts versus I/Ic](image)
Single Quantum
superconducting nanowire single photon detectors

- **Low noise:** dark counts can be reduced to <10 Hz.
Single Quantum
superconducting nanowire single photon detectors

- High time resolution: < 40 ps time jitter
- This Dutch company is developing and producing these detectors
- It operates with a closed-loop cryostat – no refilling etc.
- Graz is checking possibilities to test it in Graz;
- Maybe a station with non-moving detector package would be a more suitable test-bed?