Demonstration of a Next Generation SLR Based on SNSPD Array

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Outline

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3. Laser ranging results

4. Conclusions
1. Background

Space debris is the collection of defunct human-made objects in earth orbit, such as old satellites, spent rocket stages, and fragments. From Wikipedia.

Satellite Laser Ranging (SLR) is most precise techniques for measuring space target such as satellites and space debris.

https://ilrs.cddis.eosdis.nasa.gov/index.html
Brief history of SLR

Solomon, L.H. (1967) Some results at Baker-Nunn tracking stations. Smithsonian Astrophysical Observatory Special Reports, No. 244, 14pp

1970s Nd:YAG laser with lid open showing frequency-doubled 532 nm green light

1990s Nd:YAG laser

2000s Single-photon avalanche diode

Effective number of objects, 10 cm and larger.

Debris Size

<table>
<thead>
<tr>
<th>Size/m²</th>
<th>0.1-1 cm</th>
<th>1-10 cm</th>
<th>&gt;10 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echo photons/10⁴</td>
<td>150 million</td>
<td>650 000</td>
<td>22 000</td>
</tr>
</tbody>
</table>

2. SRL system and SNSPD

Propose: 1064 nm laser + SNSPD

- Laser wavelength: 1064 nm
- Laser pulse energy: 0.4 J
- System equivalent focal length: 2352 mm
- Telescope aperture: 150 mm
- Laser divergence: 85 urad
- Divergence of transmitter-telescope: 97 urad
- Tracking error of transmitter-telescope: 243 urad
- Divergence of receiver-telescope: 24 urad
- Tracking error of receiver-telescope: 243 urad
- Detection area: 40 μm × 40 μm
- Coupling fiber: Ø100 μm
- Atmosphere transmittance: 0.1
- Transmitting optical system efficiency: 0.8
- Receiving optical system efficiency: 0.6
- Target reflection index: 0.5

SNSPD array

Laser pulses were transmitted through a telescope with an aperture of 0.53 m. The echoes reflected from the targets were coupled to the SNSPD device through the 1.2 m-aperture telescope.
**Schematics**: SLR system

- 1064 nm SNSPD
- Beam compression
- Quasi-gated model

L. Xue, et al., Optics Letters **41** (16), 3848 (2016);
L. Zhang, et al., IEEE PLT, **28** (22), 2522 (2016)

Detection area: 40 um
Beam compression: ~0.3X
NA: 0.8

Coupling Fiber: 100 um
NA=0.22

Telescope: 1050 mm
Diffraction Spot size: 37 um
Tracking error: 242 urad
Equ. focus length: 2352 mm
1064 nm SNSPD on MgF$_2$ substrate

MgF$_2$ $n_0=1.37$

Absorption (%) (b)

$A_{\text{max.}}=99.0\%$

Index

Wavelength (μm)
SNSPD array

- Uniformed geometric structure and electrical properties.

2×2 SNSPD

SEM images of nanowires

IV curves at 4.2K
System performance of SNSPD array

Channel 1#

Channel 2#

Channel 3#

Channel 4#

DE (%) vs Bias current (μA)

DCR(cps) vs Bias current (μA)

Time jitter: 140 ps

T=2.2 K
3. Laser ranging results

- Cooperative target: COMPASS I6B Satellite

- Echo rate
  - Peak: 50%

- Flight path

- Altitude: 36,000 km
Non-Cooperative target: debris No. 37766

Large deviation from the prediction and large vibration.

Altitude: ~700 km
Resolution of SLR

Width of laser pulse: 6.7 ns

Most width was attributed to the laser pulse.
Comparison with previous results

An old rocket body (NORAD 23088), detected at the SLR station Wettzell.

NOT only high efficiency, but also low noise and higher time resolution.

Analysis of ranging capability

Cooperative targets

Non-cooperative targets

Simulation was conducted based on Lidar equation. The results was consistent with experimental data.
4. Conclusions

- Demonstrated a next generation of SLR based on SNSPD.

- High echo rate for GEO satellite and space debris.
  
  We have measured 170 targets up to now. (95% success)
  
  This system is possible to measure the debris with size < 10 cm.

- The ranging capability can be further improved with a better telescope.
Thank you!

Any comments are welcome. Lzhang@nju.edu.cn