NV-based Quantum Spin Register with Plasmonic Readout

- Spin contrast readout in plasmonic environment?
- Precise scalable positioning of nanodiamonds
- Integrated single-photon detector
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S. Bogdanov et al, PRB (2017)
NV center spin preparation and readout

**Optical initialization**

- Spin polarized into the spin-0 subsystem
- Higher fluorescence

**Spin thermalization after $T_1$**

- Spin partially relaxes into 1
- Lower fluorescence

The change in fluorescence quantifies the spin populations

**Spin contrast**

$$ C = \frac{R_{\text{init}} - R_{\text{relax}}}{R_{\text{init}}} $$
Purcell effect on NVs in nanodiamonds

NVs in nanodiamonds dispersed over plasmonic and dielectric substrate areas

Fluorescence and spin lifetimes for NV centers on plasmonic and dielectric substrate areas
Spin contrast VS fluorescence lifetime

Contrast measured through spin decay

Contrast values:
Spin decay vs Rabi $\pi$-flip

$$C_{T1} = \frac{2}{3} C_\pi$$

Optical spin readout from NVs in nanodiamonds requires careful engineering of Purcell enhancement
NV center electronic levels

Higher fluorescence

Lower fluorescence

SPIN CONTRAST

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- **Precise scalable positioning of nanodiamonds**
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Hybrid Electrothermalplasmonic Nanotweezer (HENT)

- Fast and precise delivery to plasmonic hotspots
- High resolution nanoparticle trapping
- Ability to immobilize trapped object
- Large scale parallel assembling

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- **Integrated single-photon detector**
Superconducting detector for VIS-NIR quantum emitters

Schematic of superconducting single-photon detector (SSPD)

SiO$_2$ layer thickness was optimized for 600-800 nm wavelength range

SSPD parameters:
- jitter 62ps (~6x smaller than in typical SiAPD), low dark counts ~0.1 s$^{-1}$ (~$10^3$ smaller than SiPAD), wide dynamic range (up to 350 Mcps; 60x broader than in Si APD)

Vorobyov et al., OMEx (2017)

See other works by Goltsman, Pernice, Hadfield, Tang, Benson
Testing SSPD in real experimental conditions

with Akimov and Goltsman groups

NV emission is collected by objective & detected by fiber-coupled SSPD

Succesfully tested SSPD on a plasmonically enhanced NV center
Take home messages

- Broadband enhancement of single-photon emission via coupling a nanodiamond NV to a multilayer metamaterial (HMM); nanopatterning improves outcoupling of plasmonic waves

- NV ensembles at low excitation: spin contrast drops with increased emission enhancement; need to optimize Purcell and to use structures with improved collection efficiency

- Rapid deterministic positioning of nanodiamonds on plasmonic structures can be accomplished by using hybrid electrothermoplasmonic effect (NAs + optical + AC)
Outlook: Integrated and Scalable Quantum Information Systems
Integrated/Scalable Quantum Information

- **Grand Challenge:**
  - Build a practical integrated platform for quantum information sharing
  - Provide safer data transfer and storage for numerous applications

- **Focus on key parameters for realistic systems**
  - Room temperature operation
  - Scalability
  - Efficiency
  - Robustness
  - Cost
Integrated/Scalable Quantum Information

- Bring together advances from differing areas on a single platform
  - Memory
  - Light-Matter Interfaces
  - Sources (single and entangled photon(s))
  - Detectors
  - Logical Gates
  - Frequency Conversion

- Device interconnection schemes to enable scalability

- Consider challenges from both a device level and a system level
Integrated/Scalable Quantum Information

- Utilize the advantages of photonics, electronics, and plasmonics to achieve high performance

- Explore new materials, new atomistic defects, and new structures to optimize interoperability and performance
Conclusions

• Current material platforms for quantum photonics

• Alternative plasmonic materials and a new hybrid platform for quantum photonics

• Enhanced single-photon sources using CMOS-compatible metamaterials

• Schemes for on-chip quantum registers

• A quantum information system for room-temperature, scalable, and integrated devices