Enhancing the QE of Niobium by Exploiting UV Plasmonics and the Superconducting Proximity Effect

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Introduction

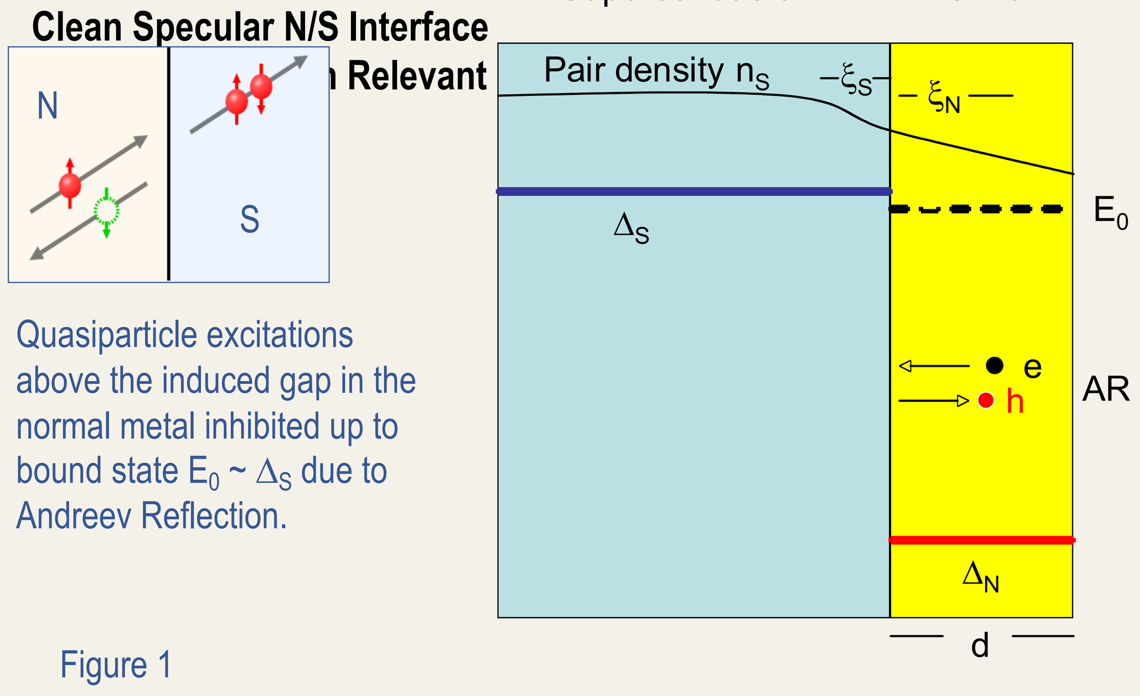
The development of superconducting photocathodes is presented which explores ultra-thin film coatings to enhance the quantum efficiency (QE) of Nb above its bulk value of < 10^{-6}, while retaining low RF losses. Major goal is coatings that are robust in air.

Two Step Fabrication Process

1.) Deposition of a 10nm layer of Mg (bulk work function = 3.66 eV) onto Nb foils (or bulk plugs) after UHV anneal. Tunneling measurements on similar foils reveals the superconducting gap close to bulk Nb. Utilize ideal Mg oxide layer for metal nanoparticles.

2.) Deposition of ultra thin islands of In (4nm thick) on top of Nb/Mg/(Mg oxide). Overall enhancements of QE by up to 400 times are found. We attribute this enhancement to **UV plasmonic effects** where the stored EM fields in the isolated In islands couple to surface electrons. Such cathodes are robust in air.

Proximity Effect in the Arnold Limit

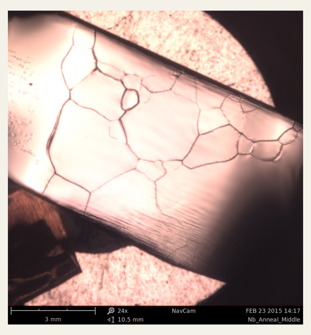


Quasiparticle excitations above the induced gap in the normal metal inhibited up to bound state $E_0 \sim \Delta_S$ due to Andreev Reflection.

Figure 1

Tunneling Spectroscopy on Nb/Mg

Recrystallized Nb foils
UHV anneal > 2000C



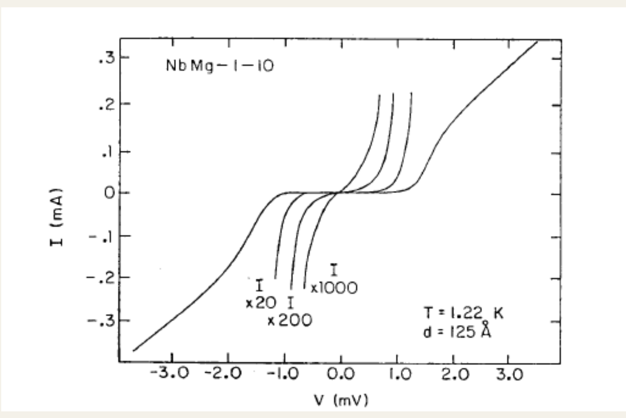


Fig.2 Representative gap region I–V characteristic for Ag–Mg–Nb junction of Mg thickness 125 Å measured at 1.2 K. Expanded traces indicate that the current leakage is less than 1/1000.

D. M. Burnell* and E. L. Wolf, "Proximity-Effect Tunneling Study of Mg" Journal of Low TemperatureP hysics, VoL 50°, Nos. 1/2, 1984

Mg is Superconducting via Proximity Effect!
Displays the Nb Gap Parameter Δ = 1.55 meV for thin layers. Anticipate same low RF losses.

Mg oxide is an ideal insulating tunnel barrier. This allows surface metal nanoparticles to be isolated but also allows weak electron transfer to replenish electrons removed by photoemission

Work Function and QE of Nb/Mg

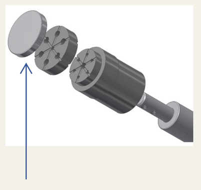
Kelvin Probe Measurements

Mg Film Thickness (nm)	QE	Work Function (eV)
0	1 x 10^{-6}	4.1
10	1.5 x 10^{-5}	3.81
100	9.0 x10^{-5}	3.7

Mg thin films on Nb approach bulk Work Function of Mg (3.66 eV).

QE increased by 10-20 over bulk Nb (see Fig. 7)

Test of Nb/Mg Cathode in AWA Gun – Phase I



- Nb plug cathode
- Mechanical polish
- UHV anneal 600C
- In situ Mg deposition
- 10 nm or 100 nm

AWA Test Gun 1.3 GHz up to 100 MV/m

Dark Current Test up to 60 MV/m

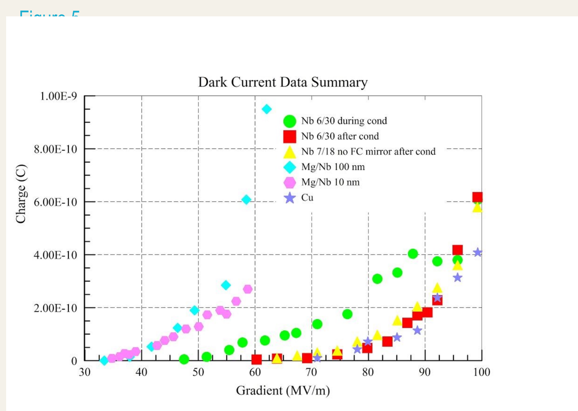
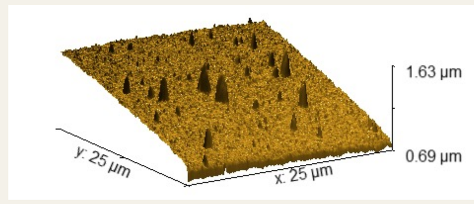


Fig. 3 Dark Charge vs E field for various cathodes

Fig. 4 AFM Topography of Nb/Mg

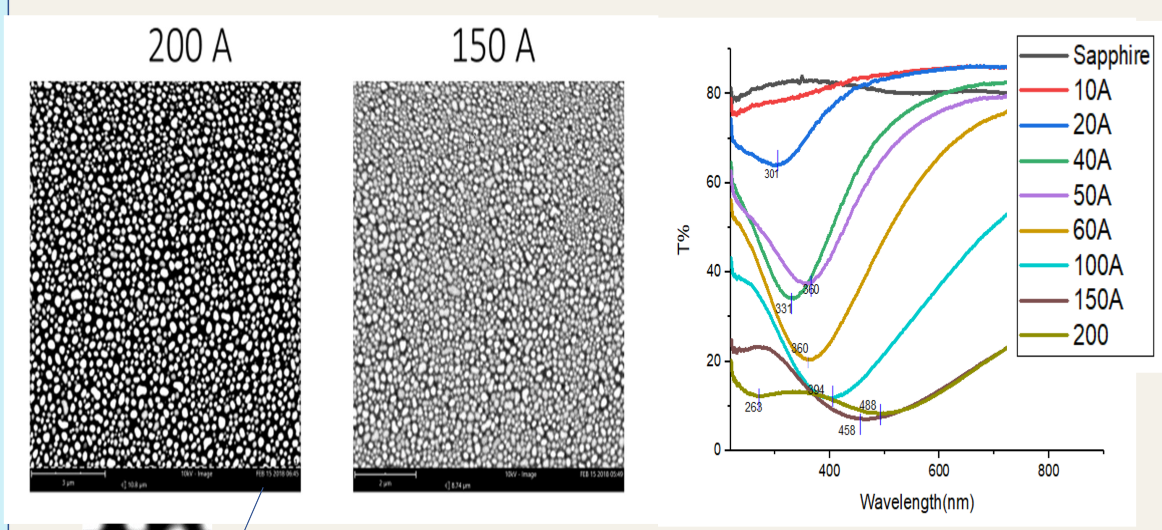


High Field enhancement, β, likely due to surface roughness (field emitters)

No significant damage to Mg layer up to 60 MV/m

UV Plasmon Resonance on Indium Islands

Optical Transmittance of PVD In on Sapphire
Surface Plasmon Mode Tunable with Nominal Indium Thickness



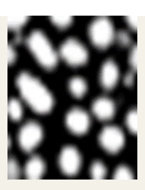


Fig. 4 Indium films on sapphire. of thickness < 200 Å display isolated island formation. Ideal for plasmonic effects. Plasmon resonances are seen as dips in optical transmittance. Tunable into UV range. Note double dip feature in thicker films.

Reflectance: In Islands on Nb/Mg/Mg-oxide

Reproducible Plasmon Mode in UV

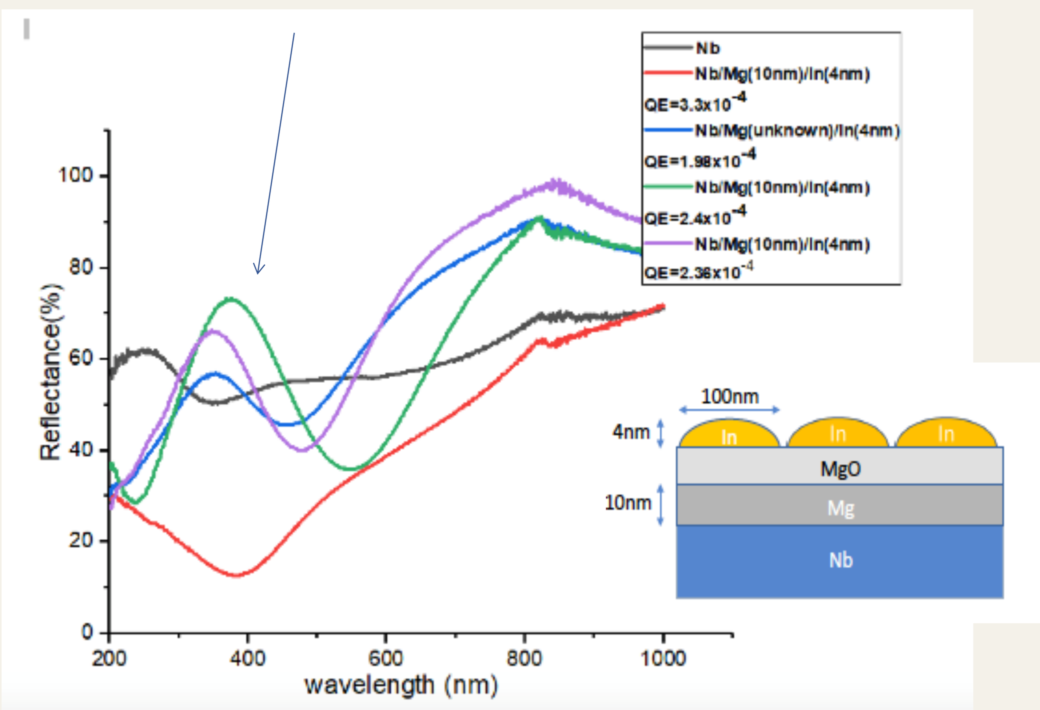
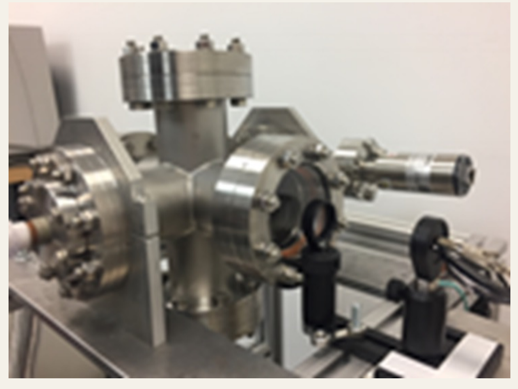
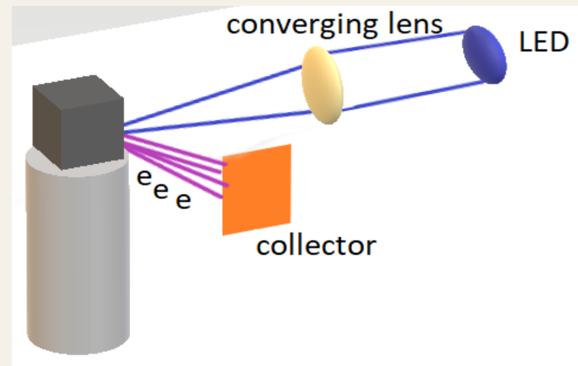


Figure 6 Optical reflectance peak is plasmon resonance. Reproducible resonance in UV range for nominal films thickness of 40 Å.

nanodisks

QE Measurement System UV LED





UV LED Wavelengths	Photon Power
245 nm	1 mW
260 nm	30 mW
285 nm	40 mW

QE Results

All Samples Exposed to Air

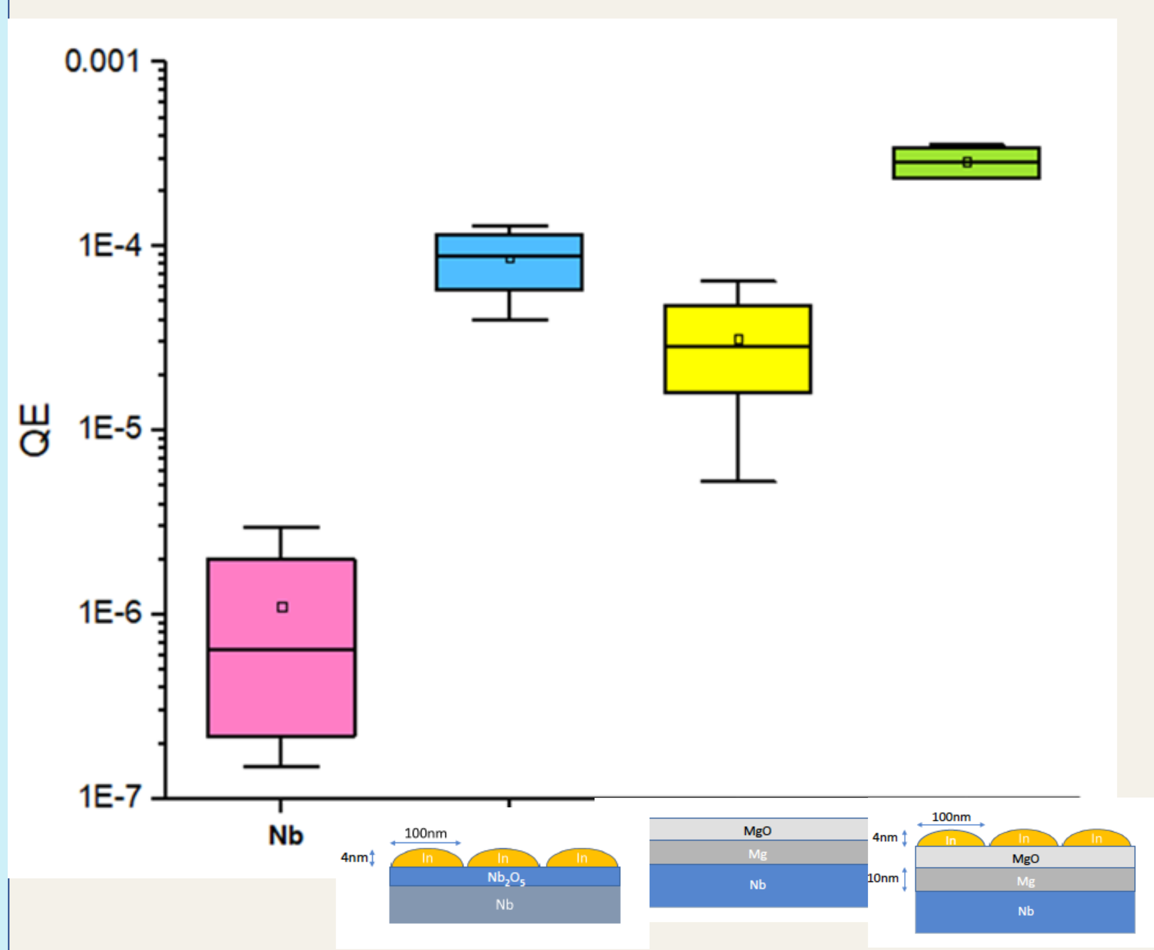
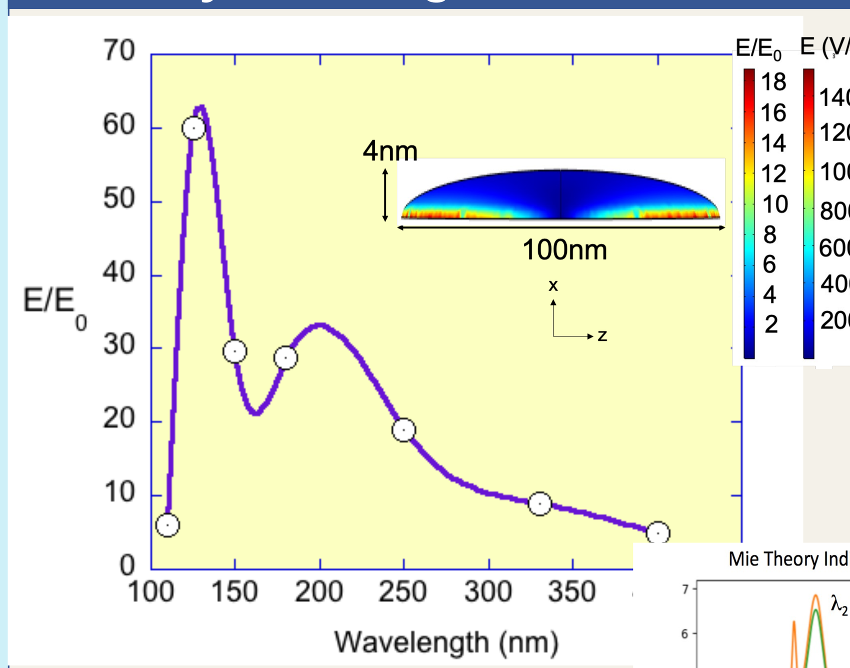
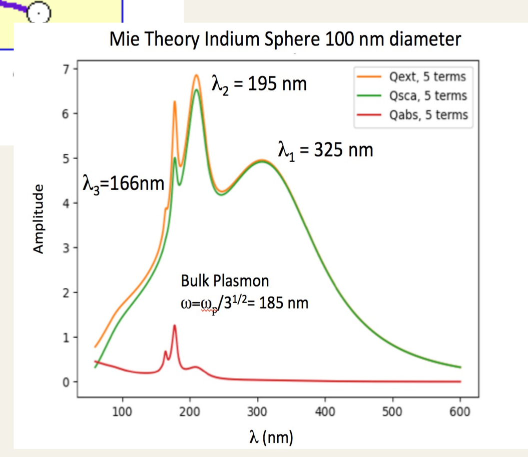


Fig. 7. QE measurements for pure Nb and various thin film Coatings. Indium islands (~ 40 Å thick) on Mg oxide show QE increase > 400 times that of uncoated Nb

Analysis using COMSOL and Mie Theory





Conclusions and Future Work

- QE of Nb/Mg is enhanced by factor of 10-20 after air exposure.
- Vapor deposition of In (4 nm thick) onto air-exposed Nb/Mg leads to QE up to 4 X 10^{-4}
- Robust in air
- Proof of principal for plasmonic enhancement
- Future: Lithographic UV Plasmonic Array

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