Introducing Nb to InAs nanowire with epitaxial Al full shell

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2 Theory of Superconducting Proximity Effect

3 Fabrication of Devices

4 Fabrication Optimization

5 Results

6 Outlook
Progress of Measuring MF

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Progress of Measuring MF

Measurements by Mourik et al indicate MF *

Progress of Measuring MF

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Soft gap $\rightarrow$ Zero bound state is not protected

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Progress of Measuring MF

Measurements by Mourik et al indicate MF *

Soft gap → Zero bound state is not protected

Why?

Progress of Measuring MF

Measurements by Mourik et al indicate MF *

Soft gap → Zero bound state is not protected
Why? - Bad interface between superconductor and nanowire**


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Progress of Measuring MF in QDev

InAs wires are grown with epitaxial Al shell*


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Progress of Measuring MF in QDev

InAs wires are grown with epitaxial Al shell*


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Progress of Measuring MF in QDev

InAs wires are grown with epitaxial Al shell*

My project: Proximitize the Al shell with Nb

Superconducting Proximity Effect

A normal conductor in good contact with a superconductor is able to conduct supercurrent
A normal conductor in good contact with a superconductor is able to conduct supercurrent.
Superconducting Proximity Effect

A normal conductor in good contact with a superconductor is able to conduct supercurrent

Coherence length determines the range of the proximity effect
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SS’ Proximity Effect

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SS’ Proximity Effect

\[ T_{C,S} > T_{C,S'} > T_{\text{measure}} \]
SS’ Proximity Effect

\[ T_{C,S} > T_{C,S'} > T_{\text{measure}} \]
Experimental Evidence of SS’ Proximity Effect

Figure: 3D experimental and 2D theoretical graphs showing spacial SS’ proximity effect

Adapted from:
Theory of SS’ Proximity Effect

Gamma factors:
Proximity strength $\gamma$ and Interface transparency $\gamma_{BN}$*

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Theory of SS’ Proximity Effect

Gamma factors:
Proximity strength $\gamma$ and Interface transparency $\gamma_{BN}$

$$\gamma = \frac{\rho_S \xi_S}{\rho_{S'} \xi_{S'}}$$

$$\gamma_{BN} = \frac{R_B}{\rho_{S'} \xi_{S'}}$$

Theory of SS’ Proximity Effect

Gamma factors:
Proximity strength $\gamma$ and Interface transparency $\gamma_{BN}$*

$$\gamma = \frac{\rho S \xi S}{\rho S' \xi S'} = \frac{\xi S n S' \tau S'}{\xi S' n S \tau S}$$

$$\gamma_{BN} = \frac{R_B}{\rho S' \xi S'}$$

Theory of SS’ Proximity Effect for Thin S’
Theory of SS’ Proximity Effect for Thin S’

\[
\gamma_m = \frac{\xi_S n_{S'} \tau_{S'}}{\xi_S n_S \tau_S} \cdot \frac{d_{S'}}{\xi_{S'}} \\
\gamma_B = \frac{R_B}{\rho_{S'} \xi_{S'}} \cdot \frac{d_{S'}}{\xi_{S'}}
\]
Theory of SS’ Proximity Effect for Thin S’

\[
\gamma_m = \frac{\xi_S n_{S'} \tau_{S'}}{\xi_{S'} n_S \tau_S} \cdot \frac{d_{S'}}{\xi_{S'}} \\
\gamma_B = \frac{R_B}{\rho_S' \xi_{S'}} \cdot \frac{d_{S'}}{\xi_{S'}}
\]

Figure: Spacial orderparameter for different gamma factors
Theory Sum Up

- Low interface resistance → Andreev Reflections → Proximity effect
- $d < \xi$ → global pair potential
- $d_{S'}$ and $R_{B}$ should be as little as possible

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Theory Sum Up

- Low interface resistance $\rightarrow$ Andreev Reflections
  $\rightarrow$ Proximity effect
Theory Sum Up

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- $d < \xi$ $\rightarrow$ global pair potential
Theory Sum Up

- Low interface resistance $\rightarrow$ Andreev Reflections $\rightarrow$ Proximity effect

- $d < \xi$ $\rightarrow$ global pair potential

- $d_S$, and $R_B$ should be as little as possible
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Idea for device

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Device Dimensions

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Fabrication Overview

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Detailed Fabrication Schedule

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Problems with Nb Contacts

First generation of devices failed

Suspct milling to destroy the resist

E-6 m
New Resist Component

Another component added to resist:
New Resist Component

Another component added to resist:
Zep has a strong mechanical resistance
Use of New Resist

No shortening

Not totally controllable geometry
Bad resistance to small Nb contacts
Fabrication Optimizations

- Making milling tests for AlO$_x$ (Using 600 volts instead of 300 volts)
- Evaporating Ti/Au on etch windows
- Using (NH$_4$)$_2$S to remove InAsO$_x$ instead of milling
- Optimizing the width of the Nb contacts
- Changing CAD design
- Quicker liftoff
Milling Test for AlO$_X$

Evaporate 20 nm Al on clean chip
Preheat Kaufmann for 2 min before each milling with closed shutter
Mill for 30 sec at 600 volts - removed 2-3 nm
Mill for 45 sec at 600 volts - removed almost all the Al

Chose 35 sec at 600 volts

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Evaporating Au in Etch Window
Etch for 9 sec at 55°C runs ∼ 80nm
Evaporating Contacts on Etch Windows

Have to be think about shadowing when designing contacts
Using \((\text{NH}_4)_2\text{S}\) to Etch and Passivate InAs

After etch put sample in 40°C \((\text{NH}_4)_2\text{S}\) for 20 min

Dry and put directly into AJA

Evaporate without milling

Have had a success rate of 4/5 which is rather good
Optimizing Width of Nb Contacts

Chose a width of 250 nm instead of 100 nm
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Quicker Liftoff

By covering parts of chip with aluminum foil, liftoff can be done in few minutes
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Latest devices

- One of several devices with most contacts having sufficiently low resistance
- Most thin Nb contacts still have bad resistance

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Measurements

- Measure Nb bar (Nb contacting 4 meanders)
  - if not superconducting, try sputter with lower power
- Measure devices in a dilution refrigerator

Further fab

- AJA2 now have Nb - Can rotate while milling → less uneven
- Make milling test at 300 volts with new preheat method
- Try even thicker Nb contacts
Thank you for your time
### Test for Nb Contact Thickness

<table>
<thead>
<tr>
<th>Device</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance to contact 1</td>
<td>24kΩ</td>
<td>GΩ</td>
<td>GΩ</td>
<td>GΩ</td>
</tr>
<tr>
<td>Resistance to contact 2</td>
<td>12kΩ</td>
<td>206MΩ</td>
<td>7.7MΩ</td>
<td>900kΩ</td>
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<tr>
<td>Resistance to contact 3</td>
<td>14kΩ</td>
<td>113kΩ</td>
<td>38kΩ</td>
<td>11kΩ</td>
</tr>
<tr>
<td>Resistance to contact 4</td>
<td>14kΩ</td>
<td>24kΩ</td>
<td>12kΩ</td>
<td>12kΩ</td>
</tr>
<tr>
<td>Resistance to contact 5</td>
<td>12kΩ</td>
<td>32kΩ</td>
<td>14kΩ</td>
<td>9kΩ</td>
</tr>
<tr>
<td>Resistance to contact 6</td>
<td>12kΩ</td>
<td>25kΩ</td>
<td>11kΩ</td>
<td>8.5kΩ</td>
</tr>
</tbody>
</table>
Conductivity vs Back Gate Voltage

a

Conductivity vs Back Gate Voltage

b

Keithley 1

Sources $V_{BG}=10\,\text{mV}$
Measures current

Keithley 2

Sweep $V_{BG}$
from -25V to 25V

BG

$5M\Omega$
Calibration of Nb Sputtering

\[ a = \frac{\bar{x} \cdot \bar{y}}{|\bar{x}|^2} \]

\[ \sigma = \sqrt{\frac{\sum_{i=1}^{N}(y_i - a \cdot x_i)^2}{N - 1}} = 5.77\text{nm} \quad 11.45\text{nm} \]
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Wire Deposition
Chip and Localization of Wires

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Material Deposition

- Evaporation - Linear movement
- Sputtering - Directional diffusive
- Milling
Missing Precision

Wetetch: The whole chip is put in etchant
**Missing Precision**

Wetetch: The whole chip is put in etchant Material

**Deposition:**

Recall device dimensions $\sim 100$nm
Resist

PMMA: Long chains of polymers
MMA: Shorter chains of polymers
Both are soluble in acetone
Resist

PMMA: Long chains of polymers
MMA: Shorter chains of polymers
Both are soluble in acetone

E-Beam breaks the chains → soluble in MIBK
Elionix can expose precision down to 20 nm
Resist

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E-Beam breaks the chains $\rightarrow$ soluble in MIBK
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