



# Novel Fabrication Process for High Quality and High $J_c$ Nb/Al- $AlO_x$ /Nb Josephson Junctions

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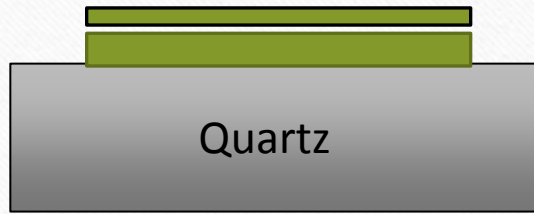
# Introduction

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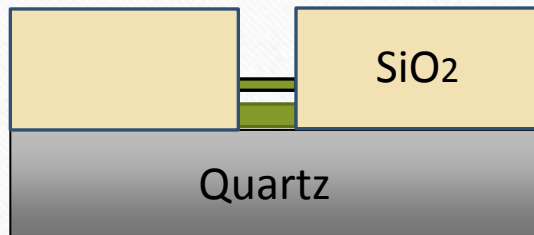
- Regular SIS Josephson junction process
- SIS junction's critical current density( $J_c$ ) and quality( $R_{sg}/R_n$ )
- Novel process of oxygen exposure
- Quality improve in high  $J_c$
- $J_c \propto (P_{O_2}t)^X$

# SIS mixer chip

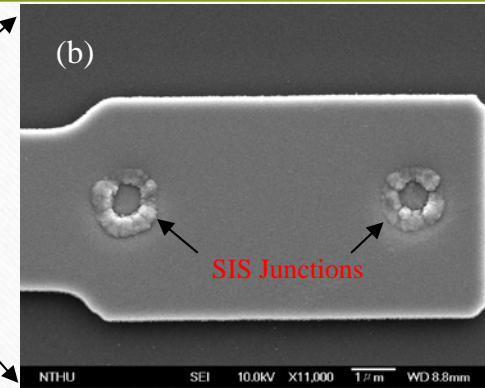
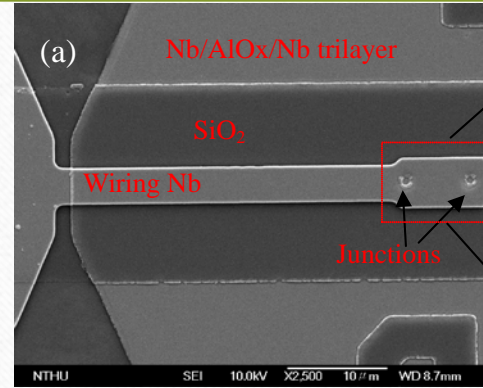
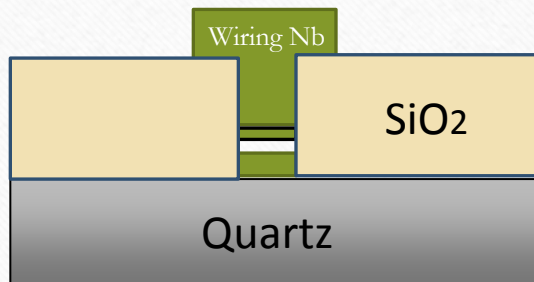
Tri-layer deposition



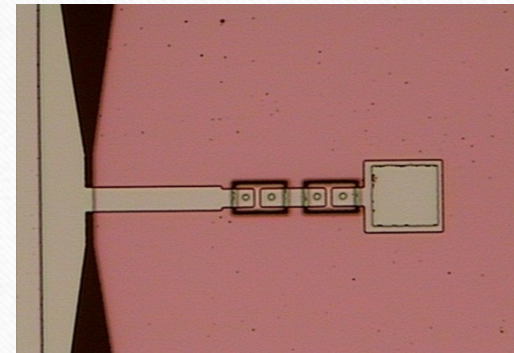
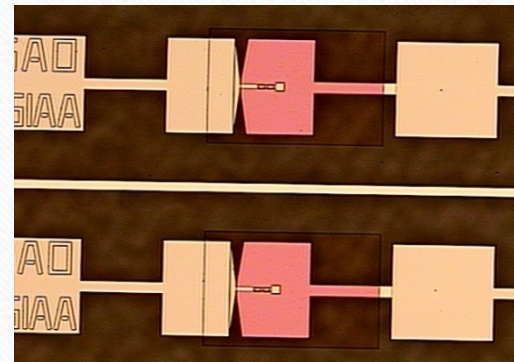
Junction definition



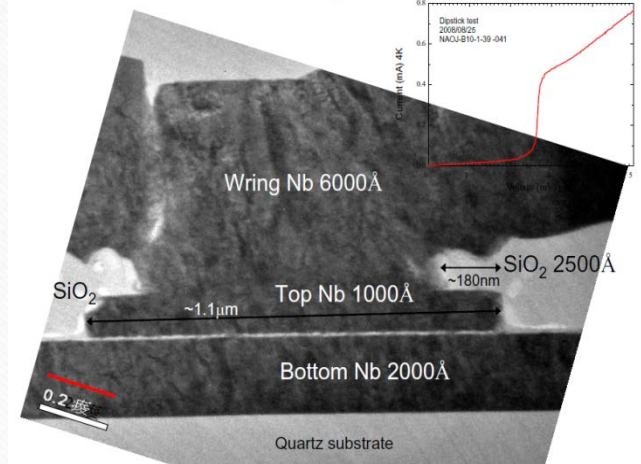
Wiring layer ICP-RIE definition



Top view of mixer chip by SEM

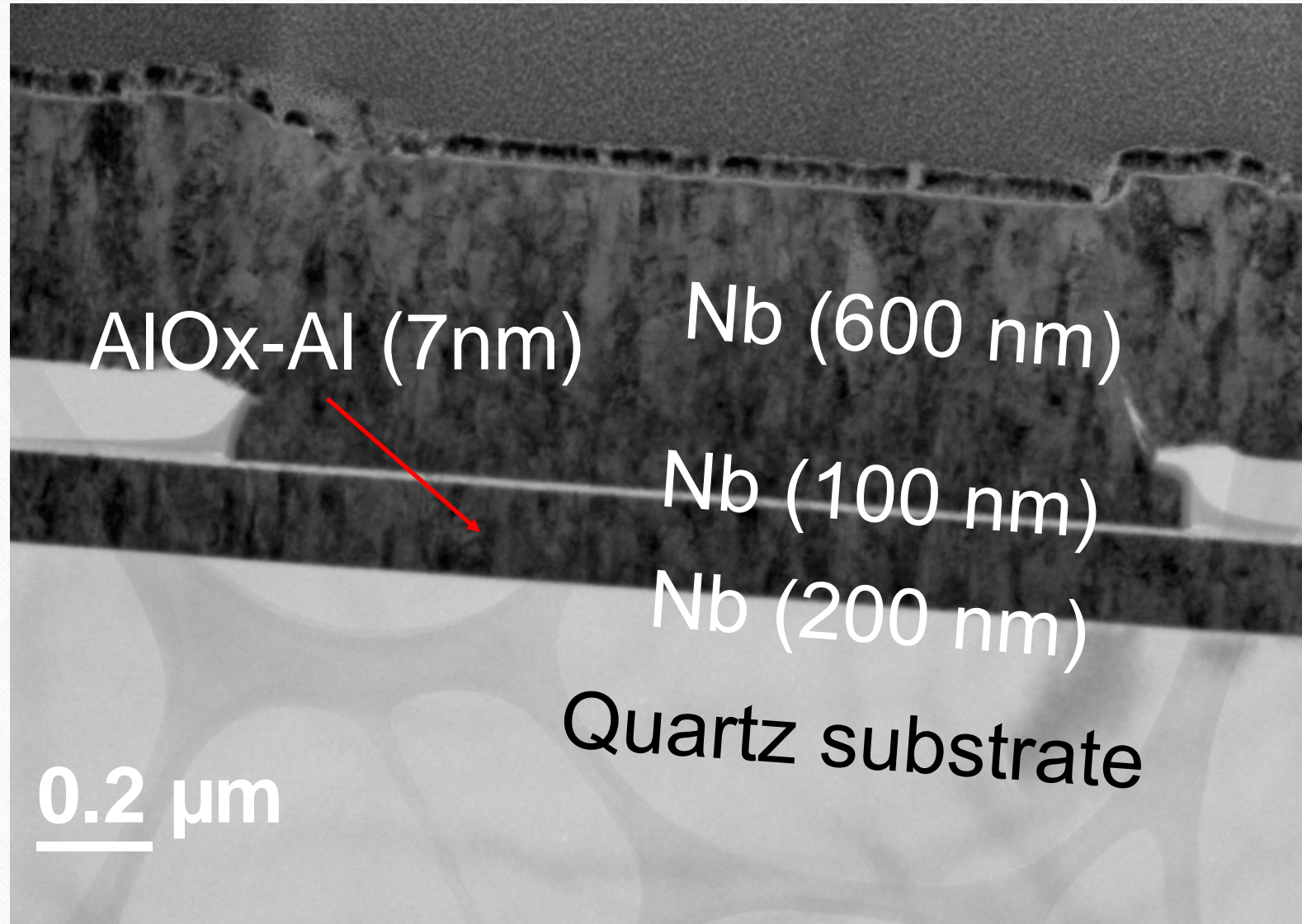


Nb/Al-AIOx/Nb junction - TEM

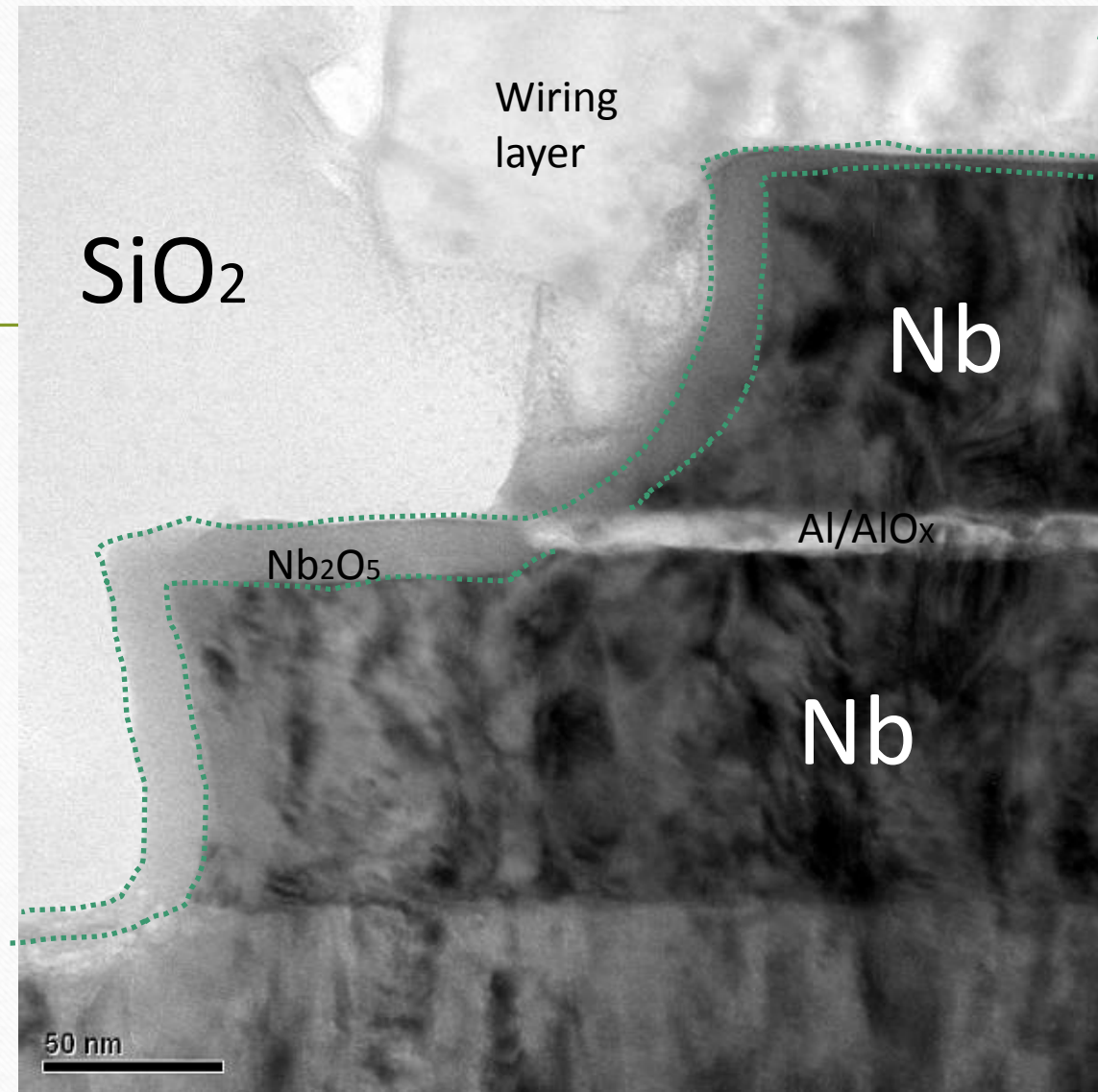


Mixer chip cross section  
OM top view of mixer

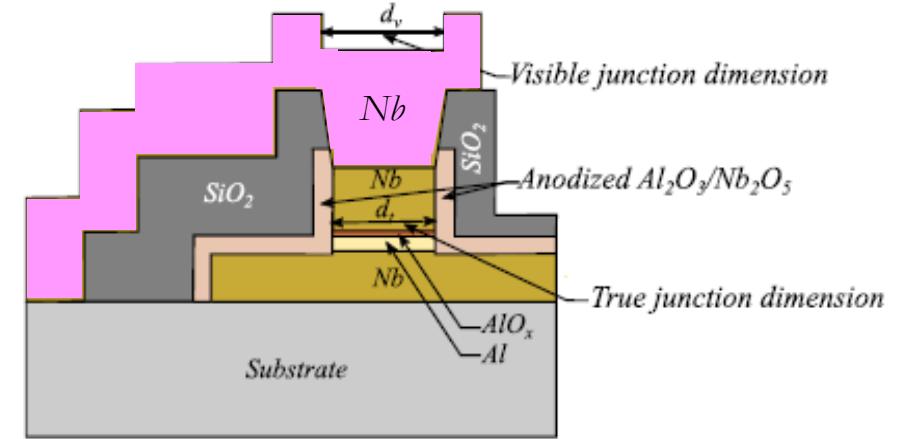
# SIS mixer cross section



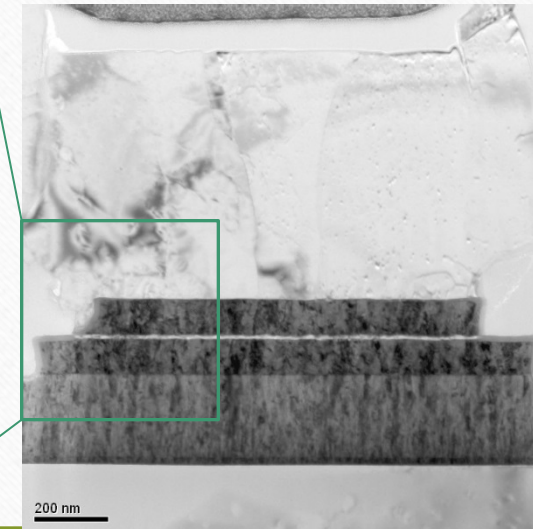
# Junction cross section



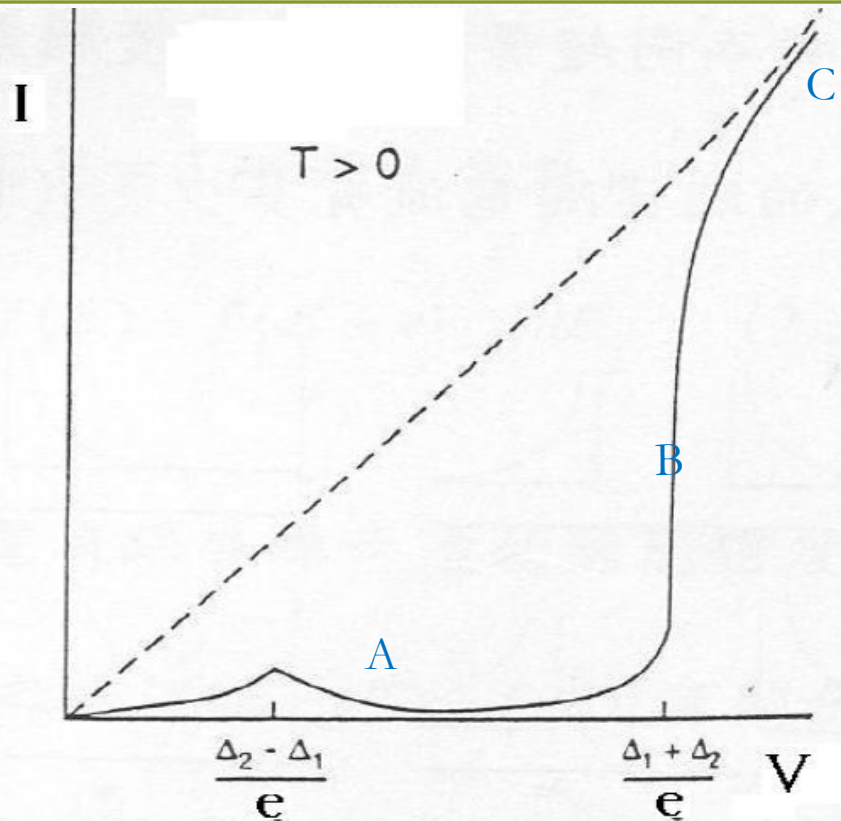
Anodized isolation layer to prevent leakage



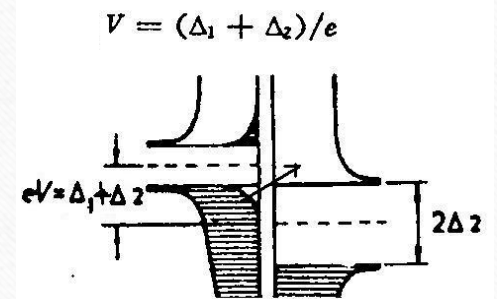
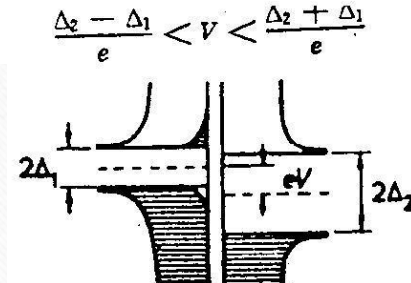
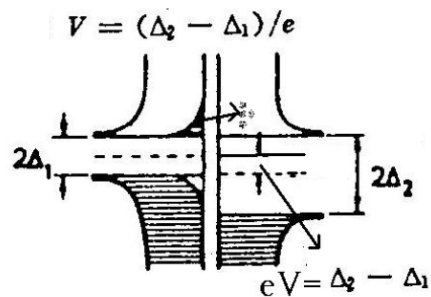
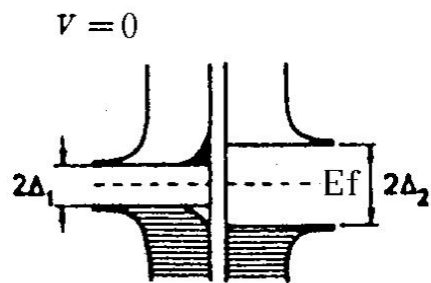
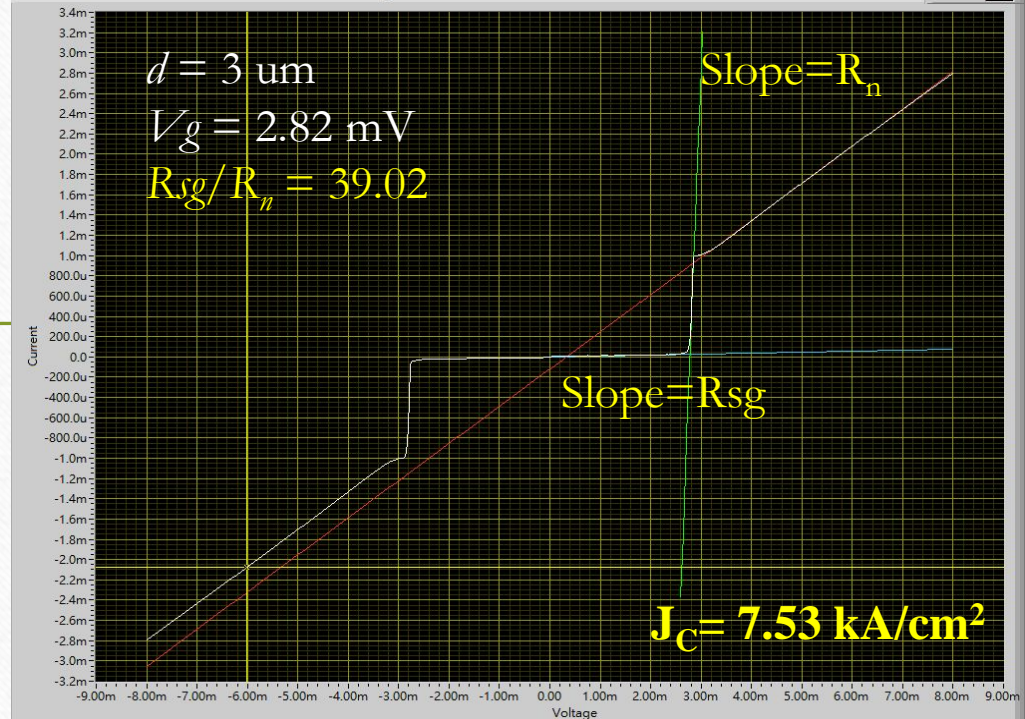
Junction size shrinkage



Junction cross section



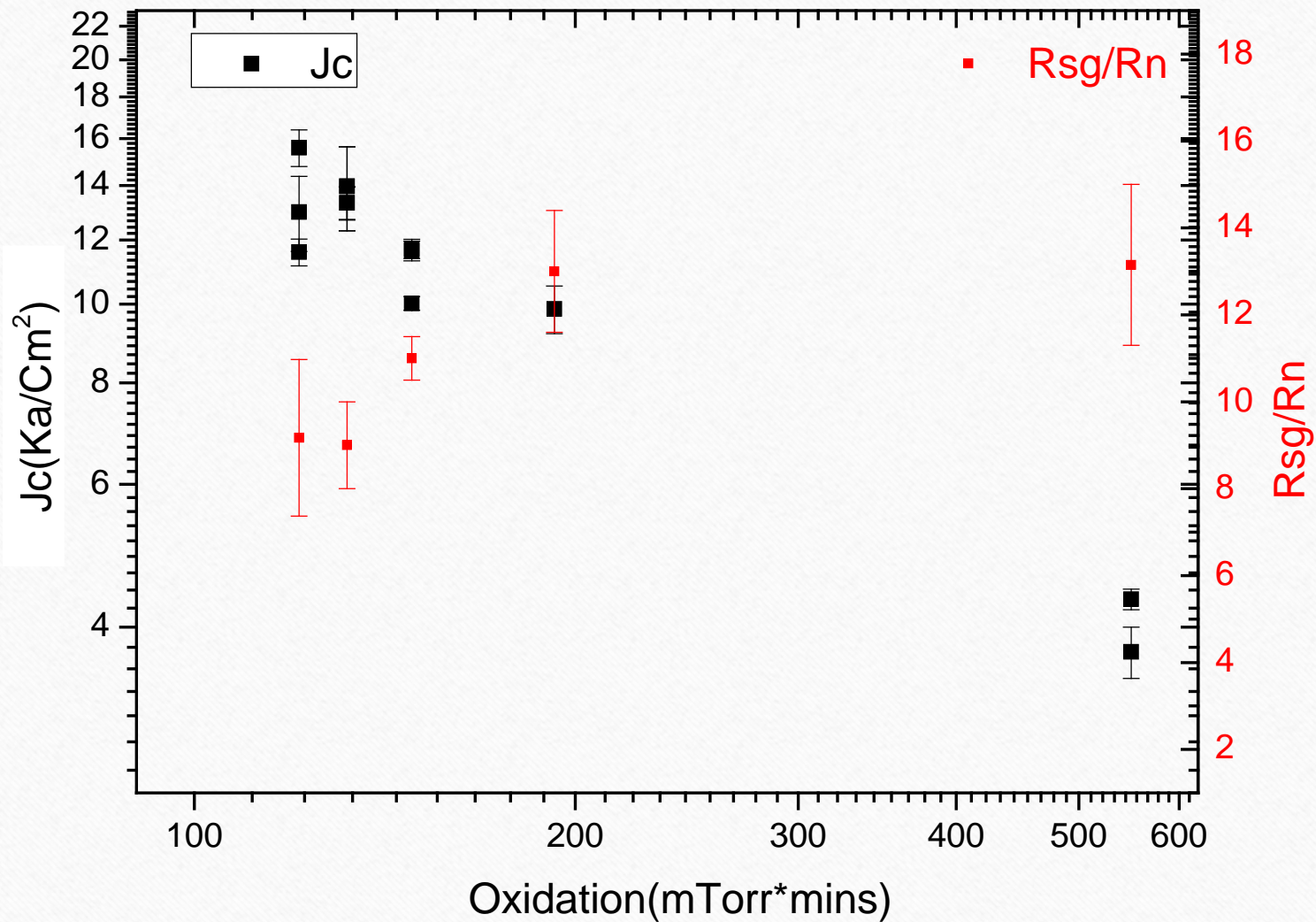
#TB1-3,  $R_n = 2.73$ ,  $V_g = 2.82E-3$ , Contact  $R = 0.08$



$V_A$  is  $eV < \Delta_1 + \Delta_2$ ,  $V_B$  is  $eV = \Delta_1 + \Delta_2$ ,  $V_C$  is  $eV > \Delta_1 + \Delta_2$ , The  $\Delta_1 + \Delta_2$  is around 2.8mV

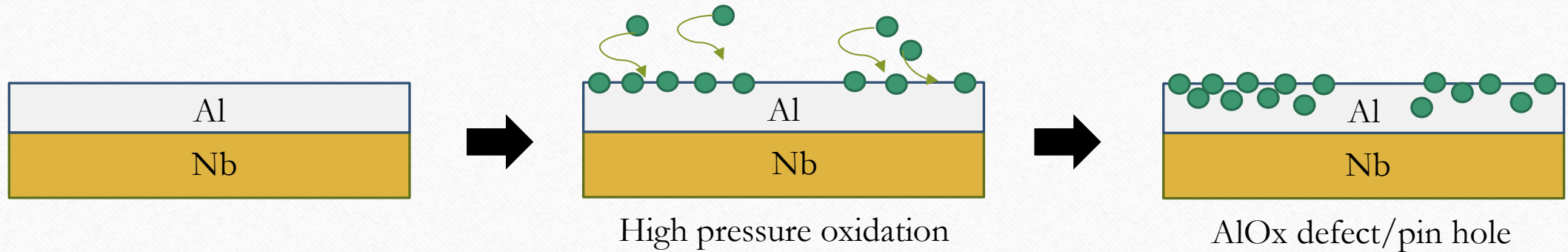
# Regular Oxidation process

Regular oxidation sample

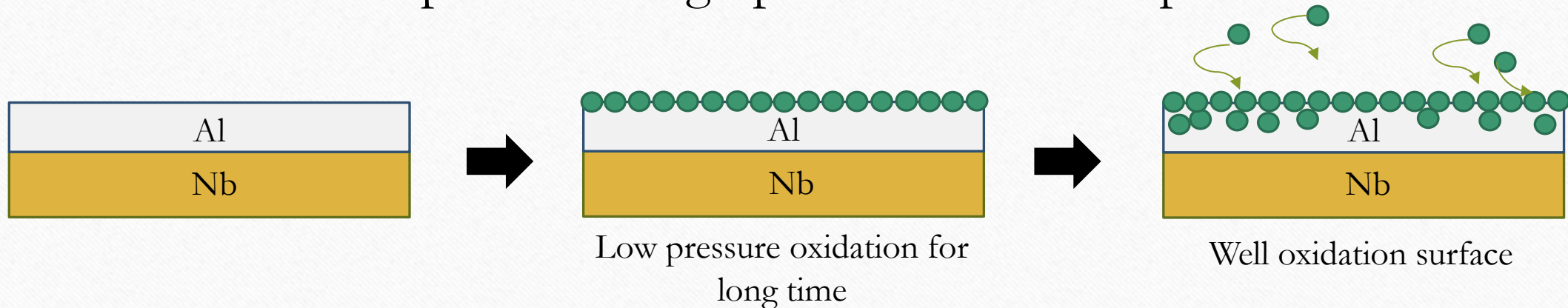


# New Oxidation process introduction

## Regular high pressure oxidation process

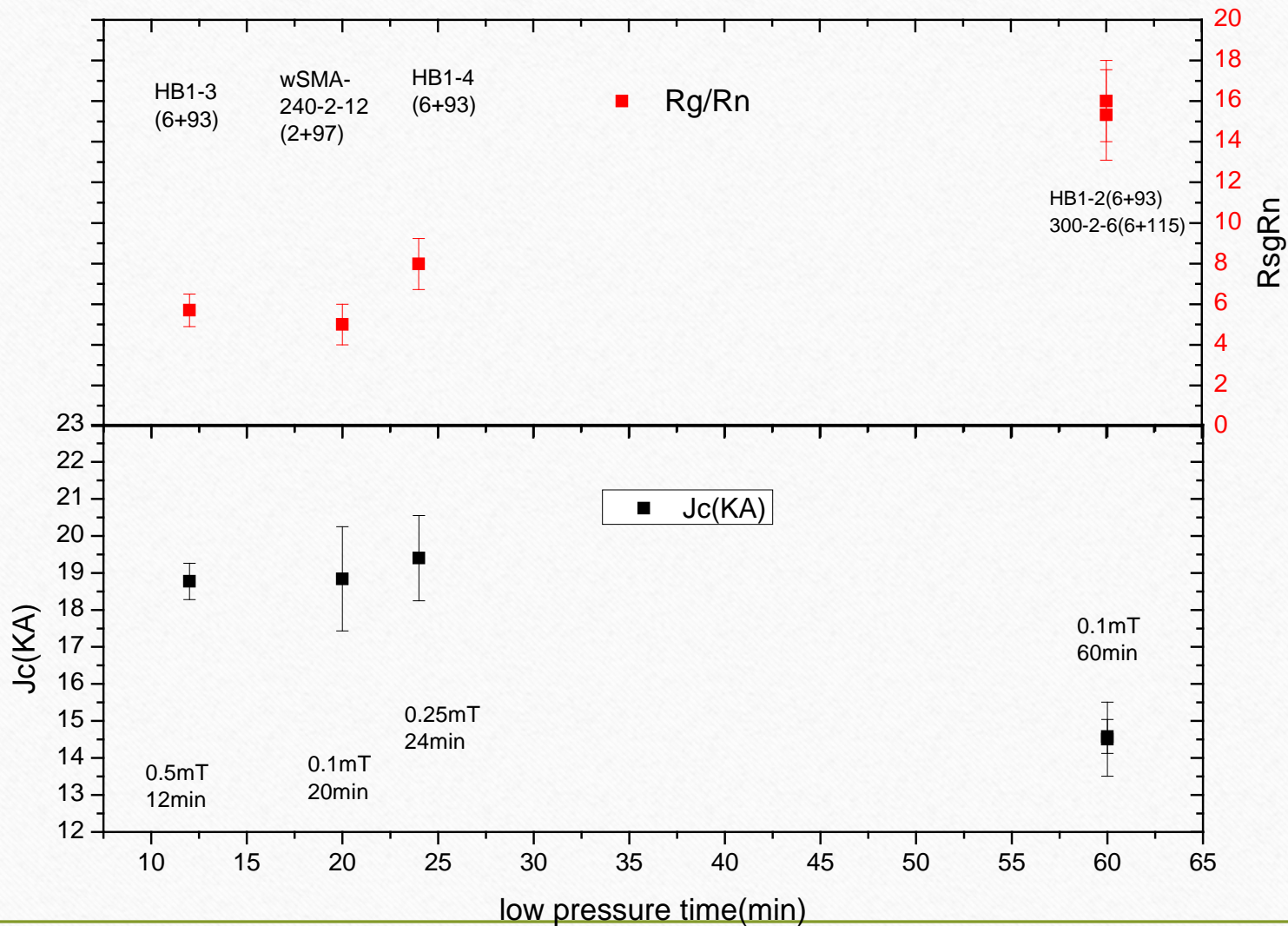


## Two step low and high pressure oxidation process



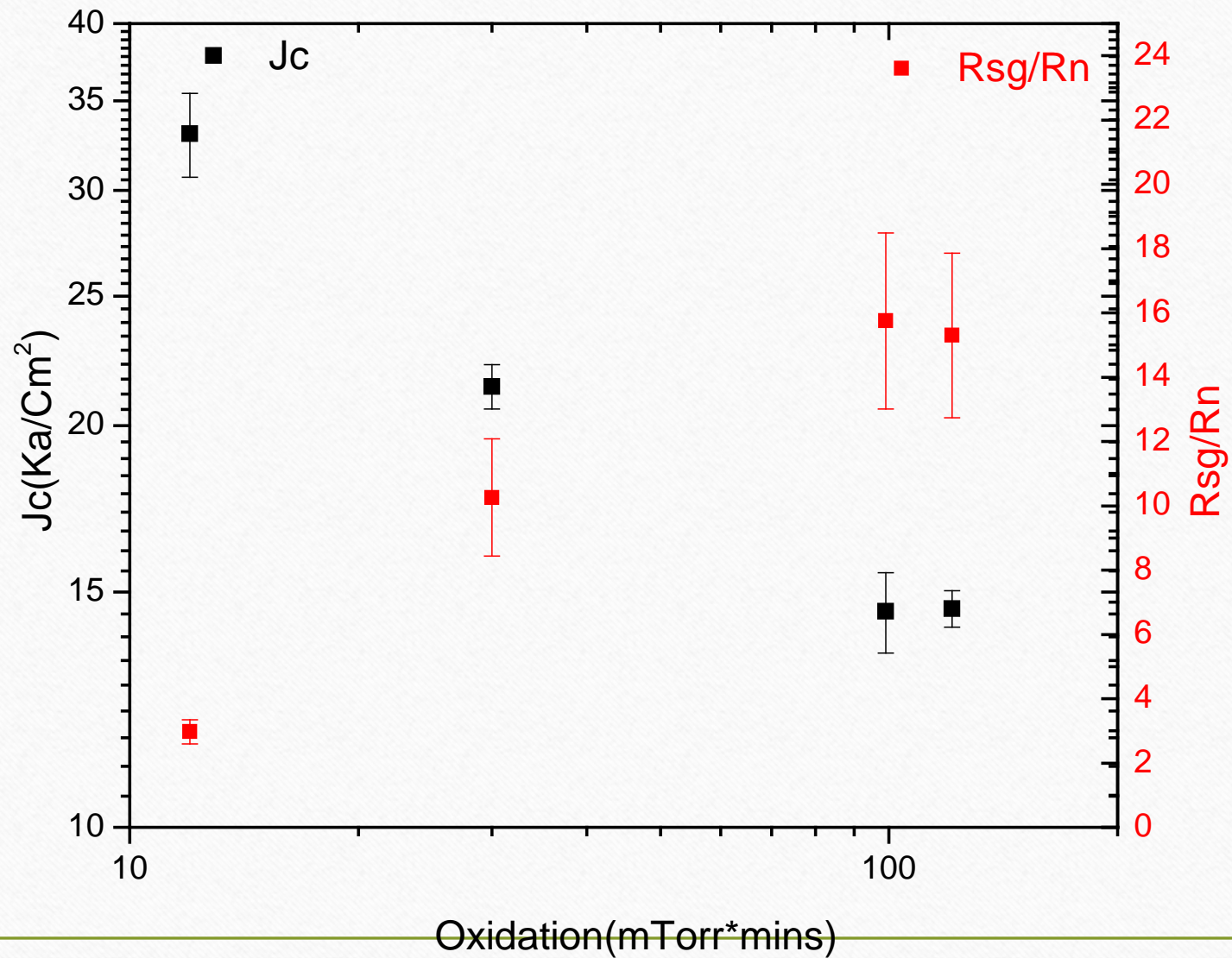
# The first step oxygen pressure effect

## Oxidation test at 99 mtorr\*mins

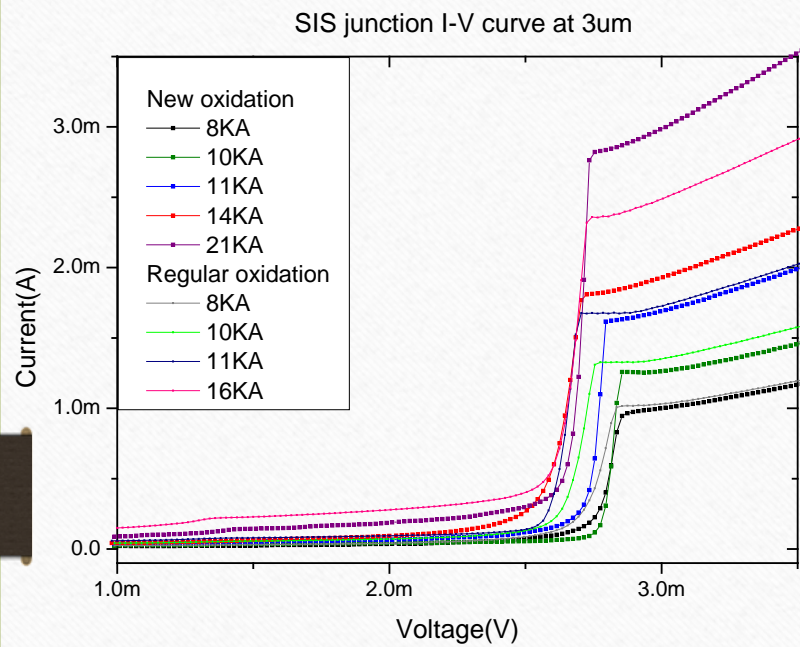


# $J_c$ and $R_{sg}/R_n$ Vs 2-step oxygen exposure

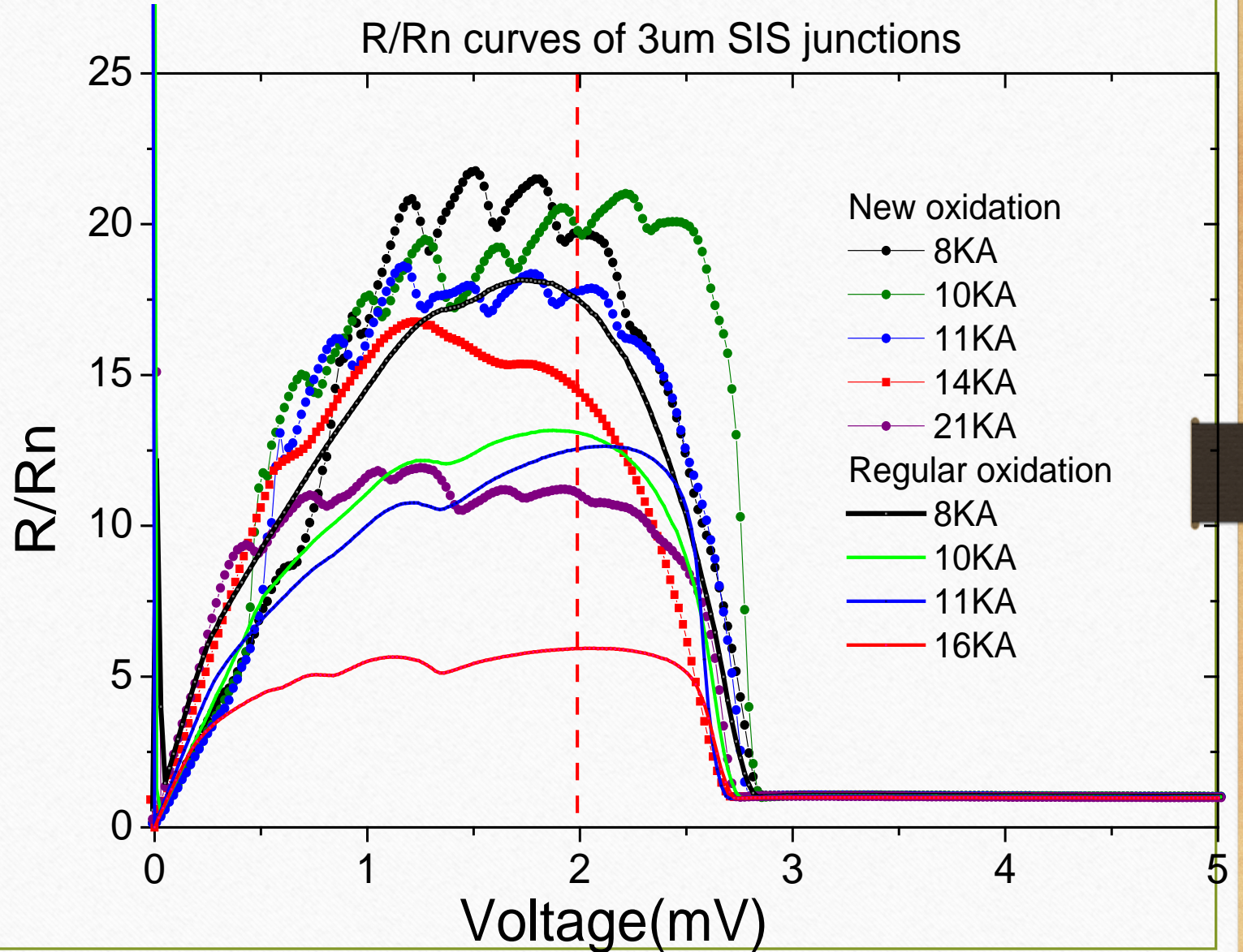
New Oxidation sample



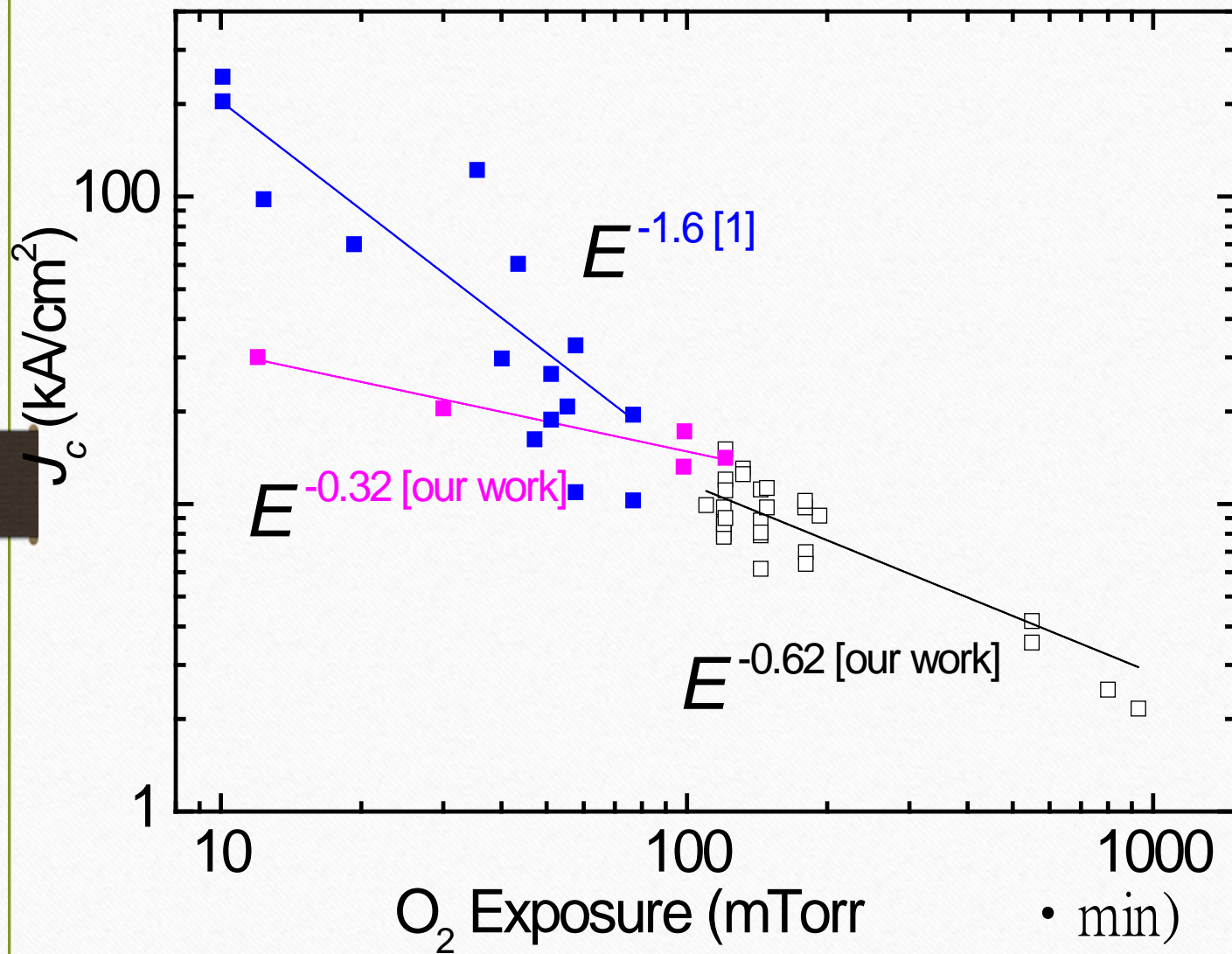
# R<sub>sg</sub>/R<sub>n</sub> curves of SIS junctions 3 μm with different J<sub>c</sub>s



New oxidation process improve the quality(R<sub>sg</sub>/R<sub>n</sub>) higher then regular.



# Jc vs Oxygen Exposure (E)



## Properties of Unshunted and Resistively Shunted Nb/AIO<sub>x</sub>-Al/Nb Josephson Junctions With Critical Current Densities from 0.1 mA/μm<sup>2</sup> to 1 mA/μm<sup>2</sup>

Sergey K. Tolpygo, *Member, IEEE*, Vladimir Bolkhovskiy, Scott Zarr, T.J. Weir, Alex Wynn, Alexandra L. Day, L.M. Johnson, *Senior Member, IEEE*, and M.A. Gouker, *Senior Member, IEEE*

(Invited Paper)

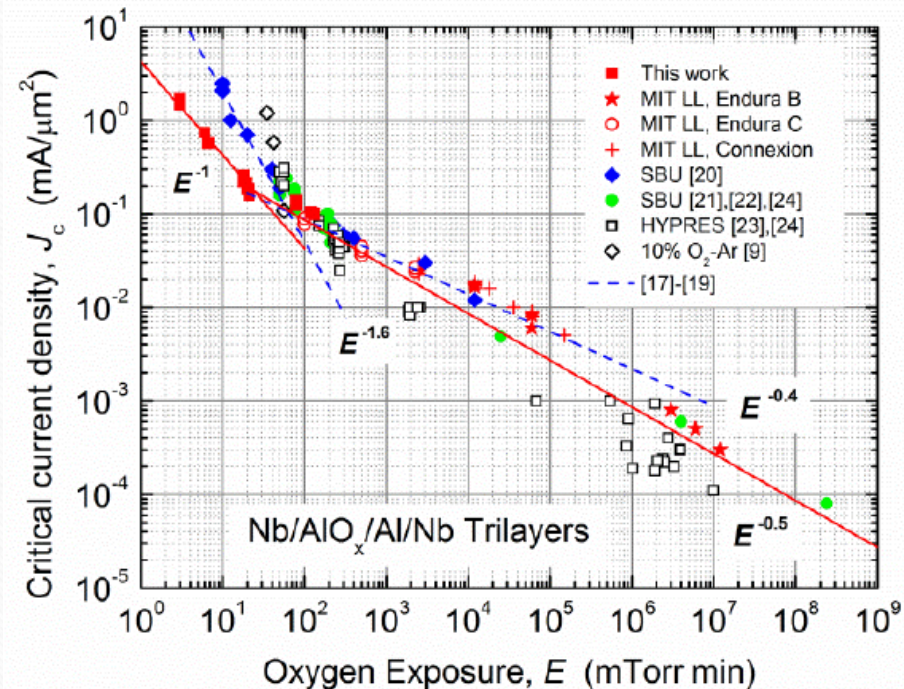
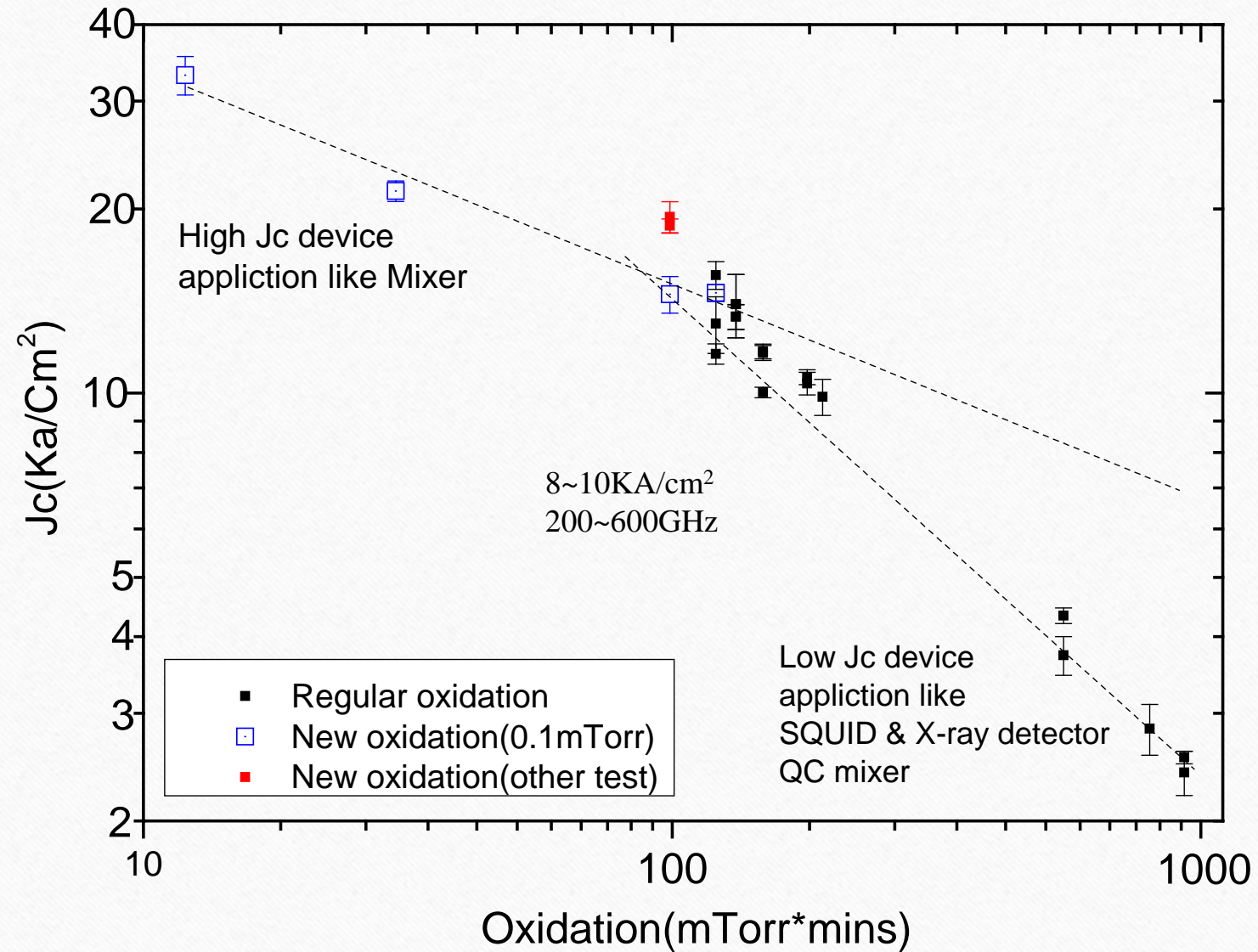


Fig. 1. Critical current density of Nb/AIO<sub>x</sub>-Al/Nb junctions as a function of oxygen exposure during AlO<sub>x</sub> tunnel barrier formation by oxidation of the aluminum layer at room temperature. Historical data from [17]-[19] are shown by the blue dashed lines, corresponding to  $J_c \propto E^{-1.6}$  and  $E^{-0.4}$  dependences. More recent data shown by blue diamonds (◆) and green circles (●) are from the Stony Brook University group [20]-[22],[24], by open squares (□) and diamonds (◇) are from HYPRES fab [9],[23],[24]. MIT-LL data are shown by the red symbols (■), (\*),(○), and (+). Our high- $J_c$  data are well described by  $J_c \propto E^{-1}$  dependence (red solid line).

# Application of SIS mixer



# Summary

- Two-step oxidation process was used for fabricating high quality SIS junction with  $J_c$  up to 21 kA/cm<sup>2</sup>.
- The  $J_c$ -E curve of the SIS junctions by two-step oxidation process has a much smaller slope in comparing with the that by regular one-step oxidation.
- Our results suggested that the very first grown AlO<sub>x</sub> has a good coverage on the Al surface under low process environment. The diffusion of oxygen into the interior Al layer becomes difficult.
- The regular oxidation in high  $J_c$ , shows ratio= $J_c \propto (P_{O_2}t)^{-1.6}$ , but the new oxidation process shows difference ratio= $J_c \propto (P_{O_2}t)^{-0.32}$
- In the normal & lower  $J_c$  range the  $J_c \propto (P_{O_2}t)^{-0.3 \sim -0.6}$

## REFERENCES

Properties of Unshunted and Resistively Shunted Nb/AlO<sub>x</sub>-Al/Nb Josephson Junctions With Critical Current Densities from 0.1 mA/μm<sup>2</sup> to 1 mA/μm<sup>2</sup> Sergey K. Tolpygo, Member, IEEE, Vladimir Bolkhovsky, Scott Zarr, T.J. Weir, Alex Wynn, Alexandra L. Day, L.M. Johnson, Senior Member, IEEE, and M.A. Gouker, Senior Member, IEEE

Thank YOU

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