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## **Assessment of Overdamped SNS Niobium-Based Josephson Junctions for Digital Applications**

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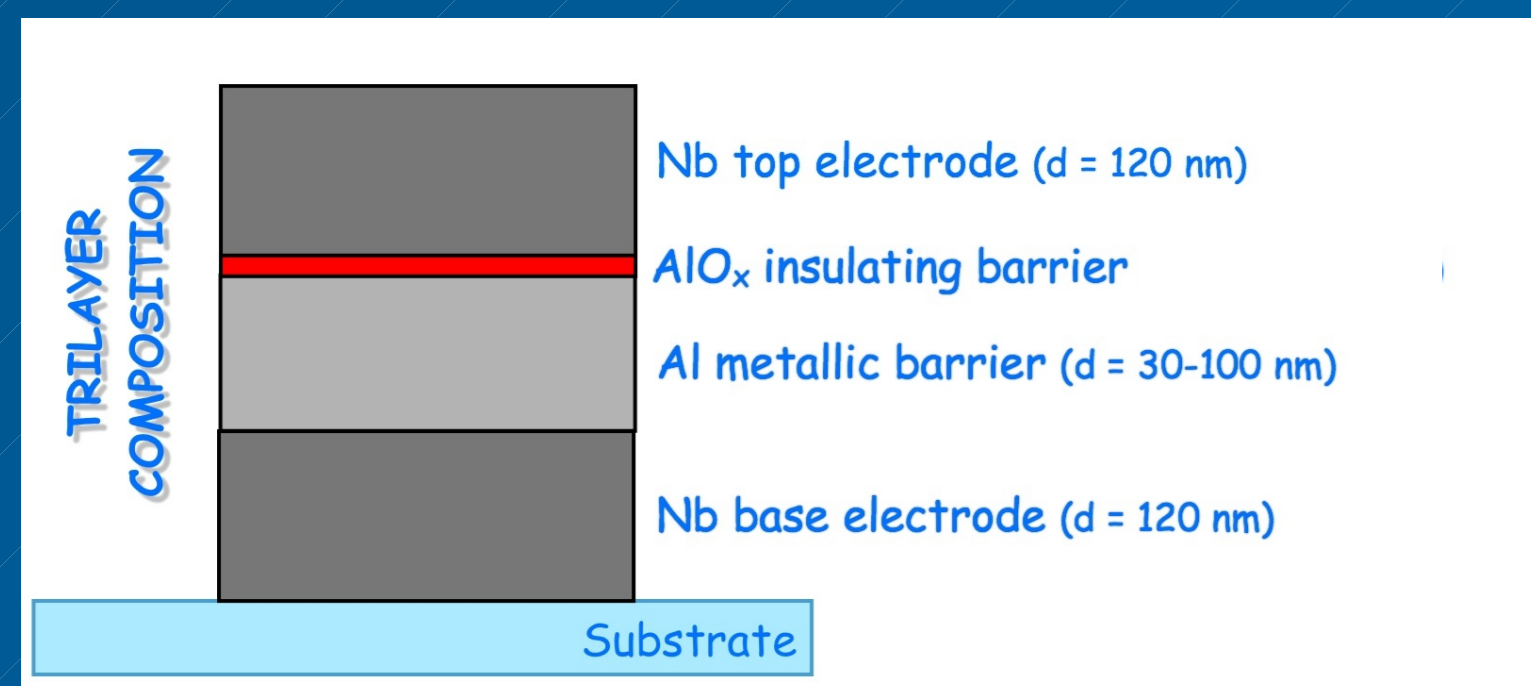


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## CONTEXT

- High current density Nb/Al-AIOx/Nb Superconductor-Normal metal-Superconductor (SNS) junctions have been fabricated with reasonably high  $I_c R_n$  products ranging between 100 and 600-700  $\mu V$
- The Stewart-McCumber parameter  $\beta_C$  can be tuned either by changing the conditions of deposition or the temperature of operation
- A determination of the Josephson intrinsic capacitance is performed to evaluate the potentialities of such internally shunted junctions for digital Single-Flux-Quantum (SFQ) electronics

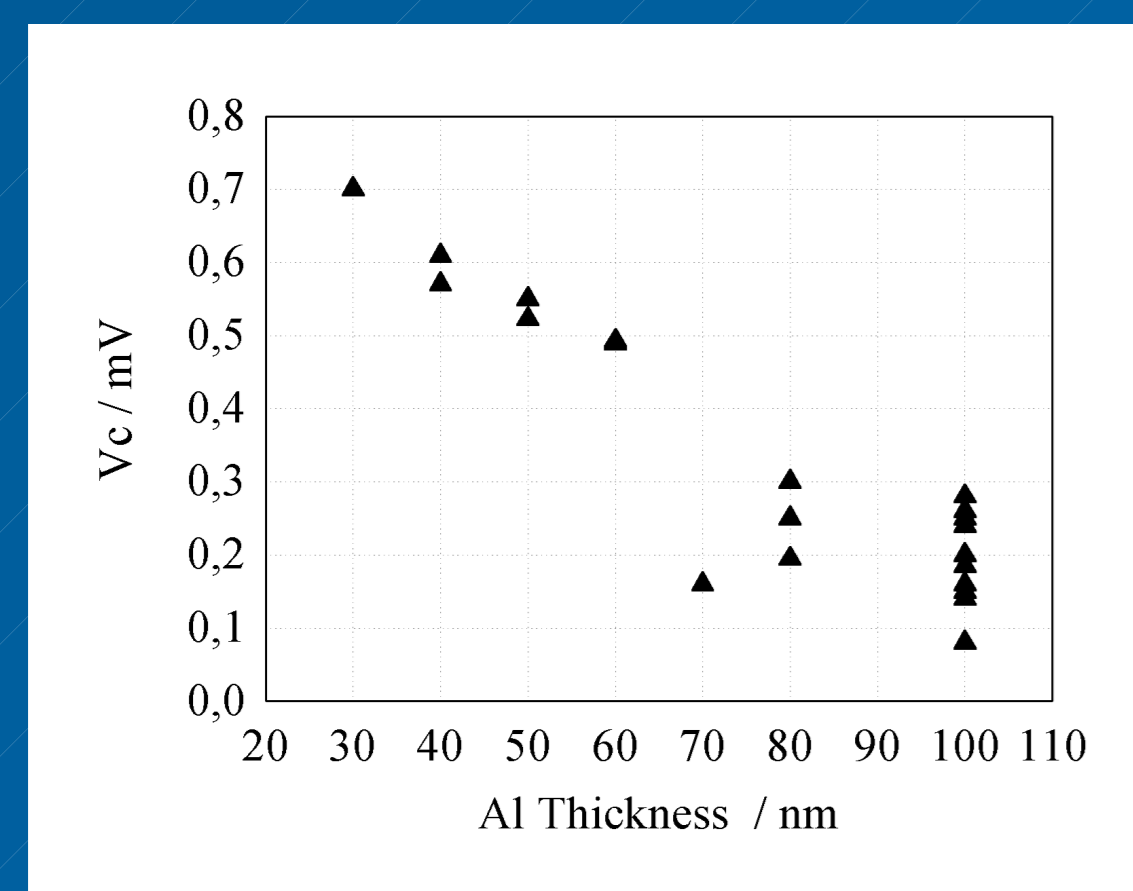
## SUPERCONDUCTOR - NORMAL METAL - SUPERCONDUCTOR TECHNOLOGY



SIS derived process

- Al thickness is 30 – 100 nm
- Oxygen Exposure (Oxygen pressure • Oxidation time) for  $Al_2O_3$  is 150 – 400 Pa • s

This results in a controlled shunting of IV characteristic as function both of the fabrication parameters and temperature.

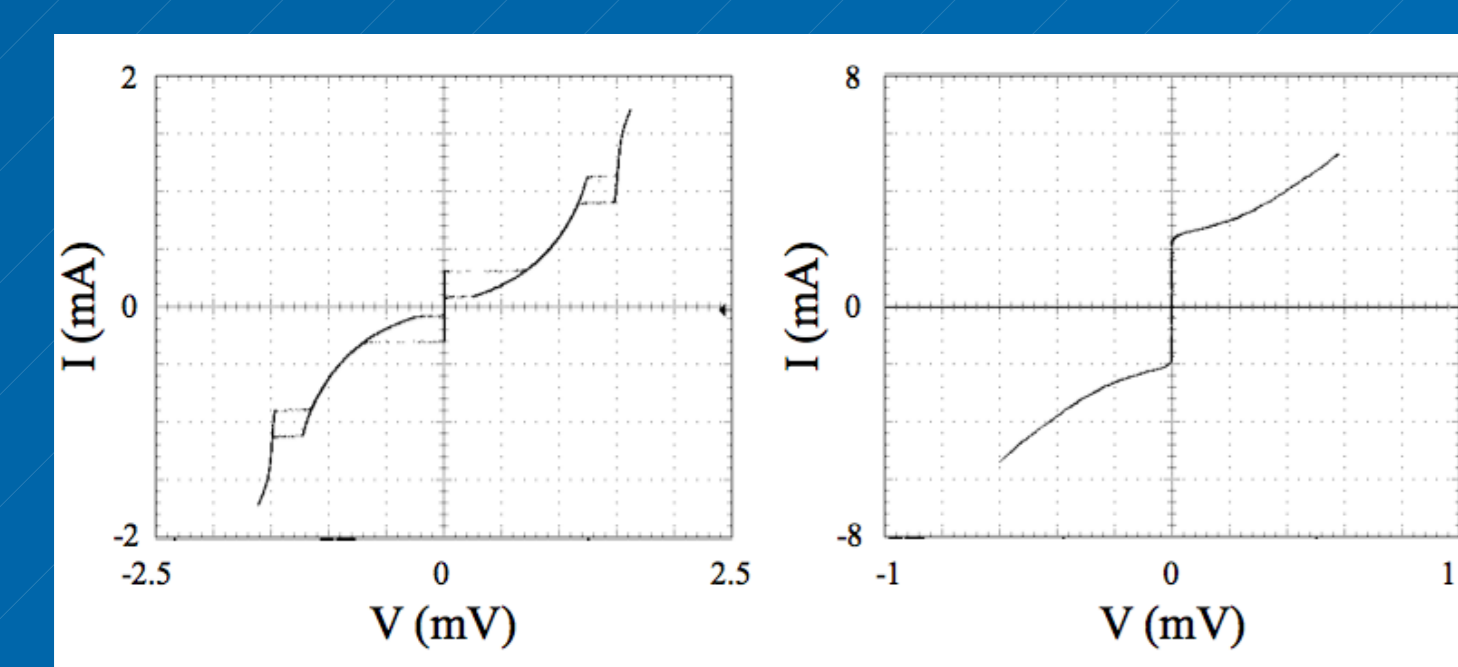


Dependence of  $V_c$  on aluminum thickness at 4.2 K

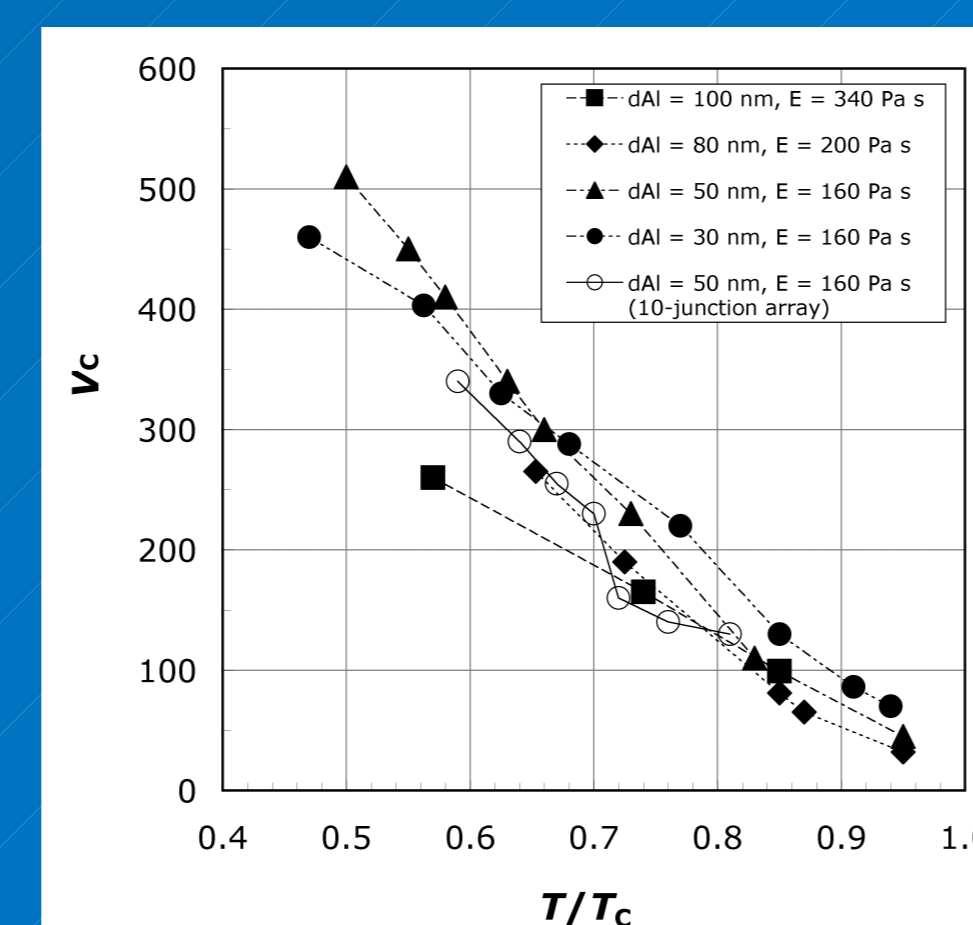
Typical electrical parameters of these junctions

- $J_c$  up to 75 kA/cm<sup>2</sup>
- $V_c$  up to 0.7 mV

## TYPICAL EXPERIMENTAL dc I-V CHARACTERISTICS



IV characteristic of two junctions with different fabrication parameters



Dependence of  $V_c$  on temperature for junctions with different fabrication parameters

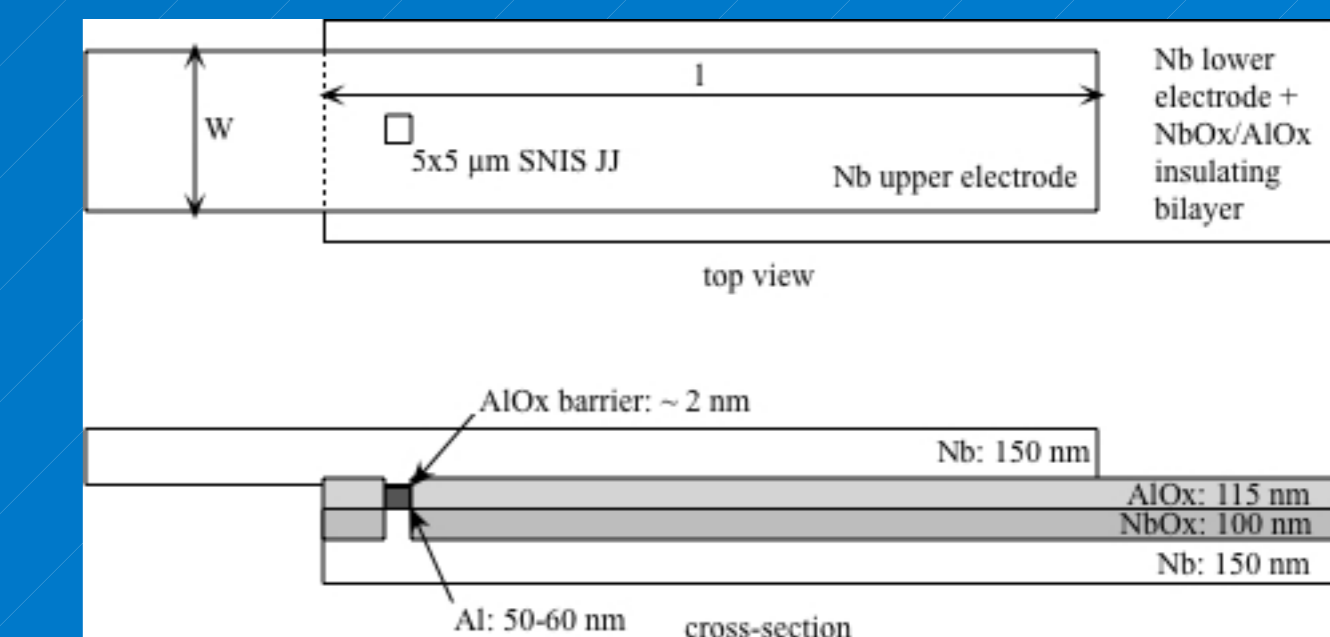
Due to the measured values of  $I_c$  and  $V_c$  these junctions can be used at  $T > 4.2K$  still producing suitable values for example:

$$T = 6 K \quad I_c = 3 mA \quad V_c = 0.3 mV$$

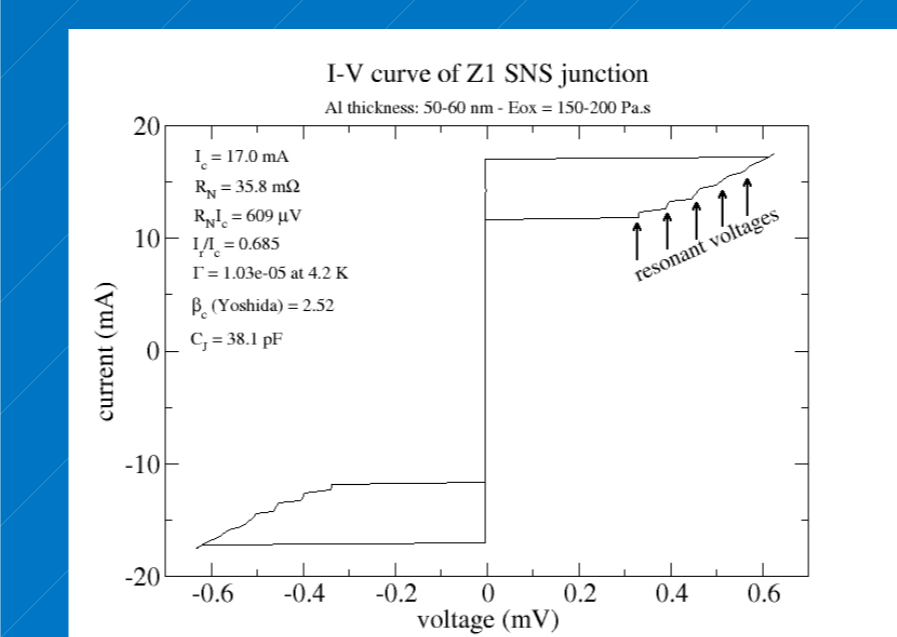
$$T = 7 K \quad I_c = 1.6 mA \quad V_c = 0.16 mV$$

## McCUMBER PARAMETER AND SNS JUNCTION CAPACITANCE EXTRACTION

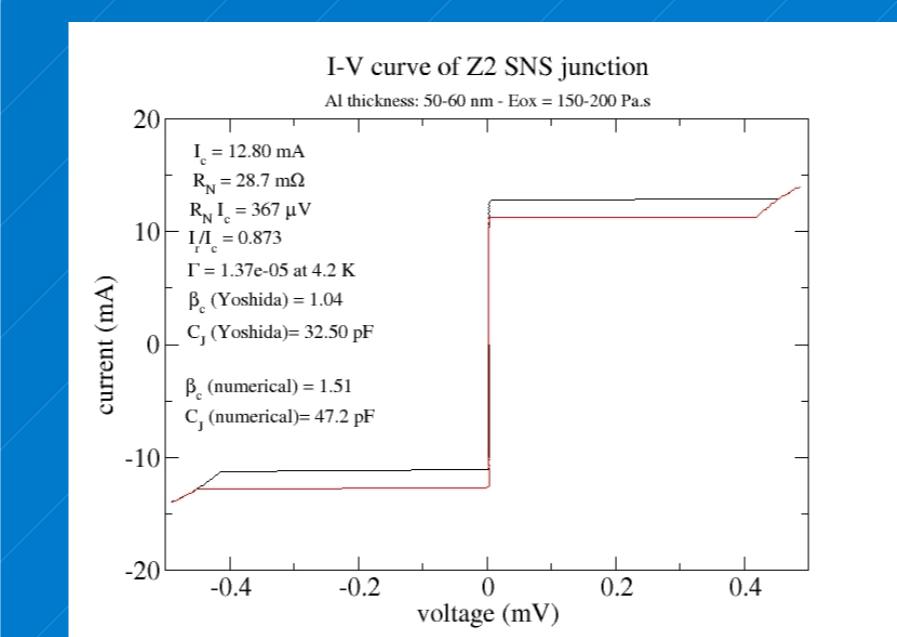
- The knowledge of the Josephson junction Stewart-McCumber parameter  $\beta_C$  associated to the junction intrinsic capacitance is crucial for digital SFQ design.
- In a first step, McCumber parameter and junction capacitance are deduced from analysis of the hysteresis of the Josephson junction dc  $I-V$  curves.
- The SNS junctions under study have been integrated with a resonant structure to confirm the value of the junction capacitance (see figure to the right).
- Resonances occur when the imaginary impedance of the resonant structure forms a tank circuit with the junction capacitance.
- Simulations have been performed with a 2.5 D numerical method based on Sonnet Software and with analytical dispersive and non dispersive models for superconducting microstrip transmission lines. Good agreement is found between the three methods. The dispersive model is a bit more precise at high frequencies (above 300 GHz) to account for the increase of the real part of the conductivity of niobium superconducting thin films. London penetration depth is assumed to be 90 nm for both niobium layers.
- Resonant frequencies (and resonant voltages given by the Josephson voltage-frequency relation) are found when the imaginary part of the tank circuit is zero.
- Values of resonances are compared with resonant peaks observed on the dc  $I-V$  characteristics of the junctions under test.



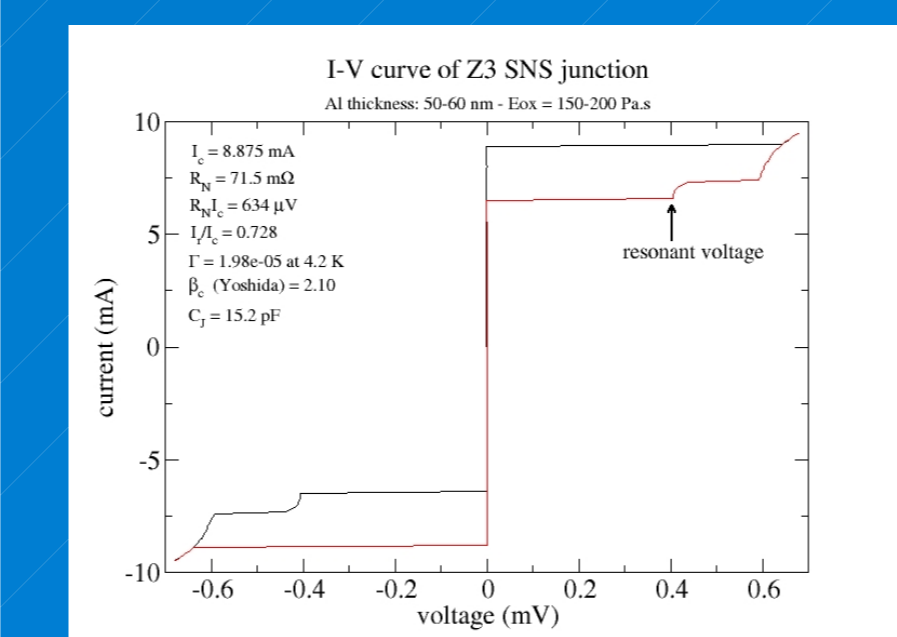
## COMPARISON OF EXPERIMENTAL RESULTS AND SIMULATIONS



Geometrical parameter	Z1 junction	Z2 junction	Z3 junction
width $W$ of resonant stub	94	90	90
length $l$ of resonant stub	880	40	190



Resonant voltage ( $\mu V$ )	Z1 junction				
measured	336.5	403	466	534	593.5
dispersive model	344.5	406	468	529	590
non-dispersive model	346	409	471	533	596



Resonant voltage ( $\mu V$ )	Z2 junction
measured	none
dispersive model	718
non-dispersive model	727

Resonant voltage ( $\mu V$ )	Z3 junction
measured	437
dispersive model	448
non-dispersive model	451

## CONCLUSION

- SNS junctions have been successfully fabricated with good  $I_c R_n$  products ranging between 100 and 600-700  $\mu V$ .
- The McCumber parameter and the junction capacitance can be tuned by changing temperature of operation and/or conditions of film deposition.
- A good agreement, within 2-3 % accuracy, has been found between capacitance values determined from dc  $I-V$  curves resonances and simulations.
- An effective dielectric constant of 16.75 has been found for the NbOx-AIOx bilayer, consistent with the dielectric constants of each film (respectively about 35 and 9).
- Such junctions appear to be usable for SFQ digital applications in a wide range of temperature up to 7-8K.
- Exact critical current densities still need to be found for junction sizes lower than the Josephson penetration depth.
- Current density needs to be tuned to achieve reasonable critical currents in the 150-400  $\mu A$  range for SFQ applications.