INRIM Istituto Nazionale di Ricerca Metrologica Divisione "Elettromagnetismo" Programma "Nanotecnologie e Dispositivi Quantistici"

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Realization of superconducting quantum devices based on tunnel Josephson junctions

Application fields

- Quantum metrology (Josephson Voltage Standard)
- Superconducting digital electronics
- Superconducting quantum computing
- High frequency radiation sensors





The Josephson junction

A device made by sandwiching a thin insulating layer between two electrodes of superconducting material. Cooper pairs can tunnel across the barrier without any resistance.



Barrier: Insulator in the simplest case, or normal metal, or other combinations like SIS, SNS, SINIS technologies

@T < Tc (Critical temperature)</pre>

The Cooper pair state is responsible for superconductivity





Underdamped Superconductor Mage resistance R Underdamped



The SNIS junction: the INRIM technology

Nb/AI-AIOx/Nb

- Intermediate state between the SIS and SNS
- Normal metal: the thick aluminum layer, is not superconductor at liquid helium temperature (4.2 K)
- Insulating barrier: a thin aluminum oxide
- Overdamped and underdamped behaviour

Electrical parameters are selected by varying fabrication parameters (AI thickness and Eox), depending on application requirements.





- CRITICAL CURRENT, I_c: current given by Cooper pairs tunneling through the junction (Critical current density, J_c (I_c/A) from 1 to 75 kA/cm²)
- CHARACTERISTIC VOLTAGE, $V_c = I_c \times R_n$, where R_n is the NORMAL RESISTANCE of the junction (V_c from 0.1 to 0.7 mV)
 - *V*_c determines the maximum output voltage of the device.

The Thin Film Technology

Thin Film Technology as a combination of different techniques

Thin film **DEPOSITION**



Sputtering

REMOVING material



Lift-off Reactive Ion Etching, RIE Device **PATTERNING**



Optical Lithography, OL Electron Beam Lithography, EBL Focused Ion Beam, FIB

nanofacility



ISO 5 (Class 100) Clean room Lab



Thin Film Technology: techniques - 1

Deposition by sputtering



SPUTTERING is a process whereby atoms are ejected from a solid target material due to bombardment of the target by energetic ions.

Sputtering system

Patterning of geometries by photolithography

PHOTOLITHOGRAPHY

is the process that transfers a pattern from a mask to a layer of photosensitive material (photoresist) previously dispensed on the substrate



Mask aligner





Thin Film Technology: techniques - 2

Lift - off

<u>LIFT-OFF</u> exploits the resist property of being soluble in acetone and selectively removes only the thin film in excess previously deposited by sputtering.

RIE (Reactive Ion Etching)

<u>RIE</u> is a dry physical-chemical etching used to remove part of thin film by reactive ions plasma that react with it. The plasma is generated under low pressure by an electromagnetic field.









Josephson device: electrical measurement set





Proposte di stage + Laurea Triennale

1) Deposizione di film superconduttivi di niobio e loro caratterizzazione elettrica (misura della

variazione della temperatura di transizione) per la sensoristica

Tecnica di sputtering (deposizione)Fotolitografia/Litografia a fascio elettronico di semplici strutture

- Profilometro
- •Misure elettriche criogeniche
- Durata: stage + tesi triennale

2) Sviluppo di un sistema di acquisizione dati per la caratterizzazione elettrica di dispositivi quantistici (LabView)

- •Misure elettriche criogeniche
- Durata: stage + tesi triennale

3) Realizzazione di dispositivi a singola giunzione Josephson a multistrato per l'elettronica superconduttiva

Tecnica di sputtering (deposizione)Fotolitografia//Litografia a fascio elettronico/Focused Ion Beam

Misure elettriche criogeniche

Durata: stage + tesi triennale



Riferimento

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The 3D FIB sculpting method





1 Volt Programmable Josephson Voltage Standard (PJVS) based on SNIS junctions

EUROPEAN IMERA PROJECT: "JOSY", Binary divided array of **8192 SNIS JJs series-connected** to reproduce the 1 Volt.





