A-Superconductivity in accelerators

Program

A1-First part (1h)

Generalities about SC in accelerators:

- where,
- why,
- cost elements

Back to basics on SC

- SC type I/type II,
- Important parameters: H_C, H_{C1}, H_{C2}, λ, ξ, κ, ℓ
- Phase diagrams…
- Normal to SC transition facts
- Theories in brief

Theories: limits of application

- London, Ginzburg Landau, Linear G.L. BCS, RF (Mattis & Bardeen)

A2-Second part: mixed state and SC properties (~ 40 min)

- Difference of behavior in RF vs DC

Vortex penetration

- Surface nucleation/Surface barrier
- Geometrical /morphologic effects
- Moving vortex/ critical current

Pinning

- Crystalline defects (recall)
- 4 mechanisms involved in pinning
- Importance of elastic strain (point defect, dislocations, grain boundaries, interfaces…)
- Pinning force/depinning energy
- Effect of frequency

A3-Third part: applications, examples of what needs to be optimized…(~ 40 min)

… in superconducting magnets

- Jc optimization
- Bean model and cable design
- Atlas, Iter, Iseult… some figures of merit

… in superconducting cavities

- Examples of designs
- Thermal aspects are dominant-
- Importance of surface states
- High gradient applications (ILC, XFEL, LCLS II…)
- Protons, heavy ions, 3rd generation light sources…
- Examples of material issues

Conclusion

B-Material and surface aspects in SRF technology

Detailed program

B1-First part: niobium, Generalities + metallurgy (~1h30 min)

Introduction

- Cavities' fabrication scheme vs surface and material properties
- Ideal Niobium cavities

Field emission & cleanliness

- Why do we need a clean room?
- High pressure rinsing (HPR)
- Multipactor

What kind of Niobium? Why bulk Niobium?

- Thermal transfer: □ $\propto$ RRR $\propto$ purity
- Titanium, Tantalum in Niobium
- Surface defects, □, and Quench

Mechanical properties of high purity Niobium

- Recrystallization: macroscopic level
- Recrystallization: temperature & time
- Specification for good forming
- Example of industrial production's problem
- Examples of Crystalline defects
- Deformation At the microscopic level
- Elastic properties

Low temperature behavior

- Issues with welding: Fragile transition?

Large grain material

- Typical sheet production
- Large grain disk preparation/forming
- Large grain material : GB issues
- Large grain conclusion

Surface state/ (electro-) chemical treatments

- Why Surface polishing?
- Short comment on surface processing (BCP vs EP) -1
- Short comment on surface processing (BCP vs EP) -2
- Alternative treatments

Surface state and roughness

- Surface State after polishing
- Real Niobium is far from ideal "textbook" superconductor
- Chemical Etching vs Electropolishing : Surface morphology effect on Quench
- Replica @ the quench site – 2D simple model
- Transition is where the field is the highest!
- Morphology effect: field enhancement
- Conformal equivalent ellipsoids and demagnetization factor
- Other 3D modeling of holes and pits
- Morphology: Conclusion

Surface damage

- Dislocations in Nb

- Main Origin of dislocations
- Damage layer seen by e- diffraction
- Deep drawing: additional strain
- After (poor) welding
- Damage and pinning
- More details on pinning mechanisms
- Grain boundaries in Nb
- Dislocation cells in Nb

1rst part conclusion

B2-Second part: Niobium, surface chemistry (~1h15)

Atomic diffusion at play

- Recall: Important defects in SC Nb
- Atomic diffusion

Surface oxide an important 2D deffect

- Surface State after polishing
- Oxide structure
- Nb2o5-x in TEM
- Oxide thickness
- Oxide behavior upon annealing
- Suboxides and XPS

Surface segregation

- Interface segregation
- Impurities @ Oxide-Metal Interface
- Surface contamination: EP vs BCP
- Niobium surface studies…
- Local segregation: experimental evidences

Interstitial oxygen and baking

- Photoemission : high resolution
- Photoemission: proof of ▯ Oi/Suboxides
- Diffuse scattering
- Baking
- Baking : @ the surface !
- Baking and SC gap
- Baking effect: PCT Results 2
- What else can we get from PCT:
- Baking & vortex penetration (by µSR)
- Baking summary

Hydrides

- Hot spots and crystalline disorder
- Hydrides & Hot spots
- Hot spots/HFQS
- Q-disease
- Hydrogen at metal-oxide interface
- Hydrides in Nb : diffusion limited
- Hydrogen in Nb and annealing
- Hydrides and baking

N doping/Infusion

- Baking/infusion
  what is the difference?
- N infusion… without N ?!
- Baking/doping/infusion
  what is the difference?
- Maybe optimum treatment is not found yet
- General scenario ?
- Hot spots: Trapped flux vs local low H_{C1} ?

2nd part Conclusion

B3-Third part: Materials for Superconducting accelerators beyond Bulk Nb (~1h15)

Choice criteria ?

- Thousands of superconductors …
- Ideal SRF material: Tailored for apps

Ultimate limits in SRF-1

- High Q0, EACC in SRF => Meissner state !
- Superheating field
- Superconductors for SRF ?
- Vortex Penetration with B //
- What is the actual limit (Hp/HC1/HSH) ?
- Vortices Avalanches
- Effects of local defects

Challenges to face on the route toward other superconductors: generalities

- General issues with SCs: depends on the strategy
- Thin films deposition techniques:
- Search for better structure

Nb/ Cu:

- Example of the issues when dealing with thin films
  - Sputtered Nb films
  - Example of Quality issues of films
  - Substrate Issues
  - Coaxial Energetic Deposition (CED)
  - Magnetometry

A2 SC alloys: e.g. NbTi

A1 SC compounds: e.g. NbN

A15 Compounds : high TC

- A15 Compounds : narrow domain of SC
  - Nb3Sn: Special interest for SRF since the 1980’s
  - Nb3Sn on Nb (thermal way)
  - Nb3Sn : non uniform layer
  - Nb3Sn : Substrates issue
  - L. M.: What else can be measured
- Other approaches

Magnesium Diboride (MgB_2)

- Magnesium Diboride (MgB2)
- MgB2 – HPCVD on metal substrates
  Hybrid Physical Chemical Vapor Deposition

- MgB2 – Other routes
- HPCVD MgB2 – RF Measurements
- MgB2 - SRF Cavity Coating
- HPCVD MgB2: Cu Tube Coating-Testing for 3.9 GHz Cavity

YBCO Family…

- not for SRF !

Pnictide Family…

- Pnictide Family… maybe yes ?

Multilayers

- After niobium : nanocomposites multilayers
- First approach: trilayers
  - Trilayers on Niobium
  - SIS Optimization: importance of models
  - Trilayer optimization (…)
- Nb – Insulator – NbN model
  - Sputtered (defective) materials…Far from perfect….
  - Comparison with theory
  - Close-up of 3rd harmonic signal
  - Role of the dielectric layer !
- MgB2-MgO Multilayer Films
  - Effect of m.f.p.
- Other results on NbN or NbTiN ML
- Nb_3Sn ML
- ML without dielectric interlayer
- Superconducting iron-pnictide multilayers

Conclusions and perspectives