European projects

- RF Panel - Thin films

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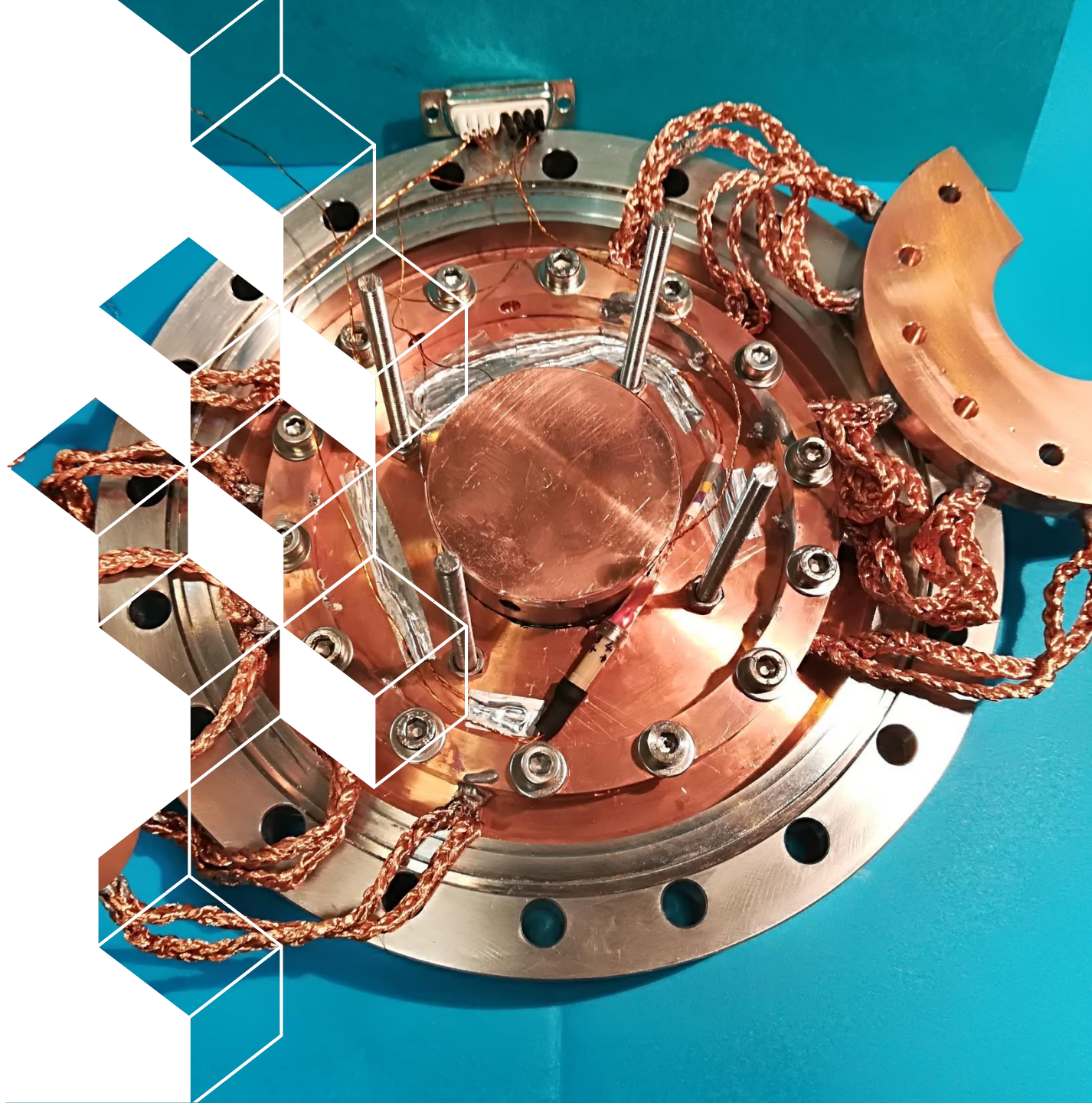


EUCARD ½, ARIES… Main results

Better understanding of a correlation between:

- substrate preparation,
- deposition process,
- thin film characterisation,
- the DC and AC SC evaluation results
- the TF behavior at RF conditions

In addition:

- Exploring other than Nb SC materials
- deposition target development
- Cu cavity production

IFAST WP9 contour

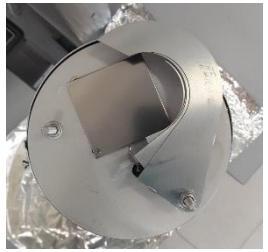
Surface preparation
- Cleaning, etching,
- Polishing, passivating

Cu sample polishing

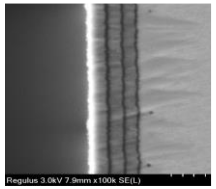
Thin film deposition
- **PVD**: DC, pulsed, HIPIMS…
- (PE)CVD, (PE)ALD
- **Nb, NbN, Nb_3Sn**, MgB_2, etc.
- Laser treatment of Nb films

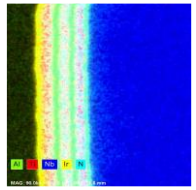
Film characterisation
- SEM, FIB, AFM,
- XPS, XRD, RBS, TEM…

Film



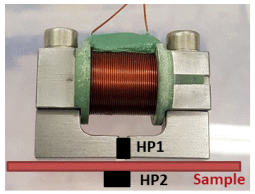
SEM and EDS images of SIS film

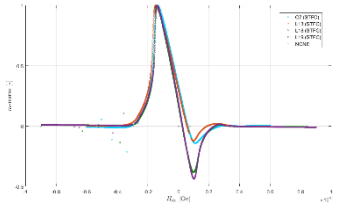




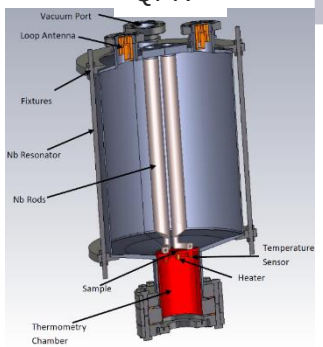
Superconducting properties measurement
- DC magnetic susceptibility,
- *RRR*, H_c, H_{fp}, H_{sh},
- Field penetration

DC magnetisation



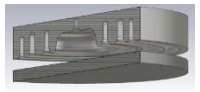


QPR



Superconducting RF properties evaluation
- QPR at CERN
- QPR at HZF
- HW cavity at ASTeC

HW test cavity



Real cavity measurement
- Cavity deposition and testing

The main emphasis is on applying the result of ARIES to RF cavity deposition and testing

1.3 GHz cavity for STF deposition

+ participation from CERN and U. Hamburg

	IFAST WP9 Partners	Leading	Participating
1	CEA (Saclay, France)	WP, Tasks 1 and 4	Task **1**, 2, **4**, 6
3	IEE-SAS (Bratislava, Slovakia)		Tasks 2-6
4	INFN/LNL (Legnaro, Italy)	Task 2	Tasks 1, **2**, 3, 5, 6
5	*INFN/LASA (Milano, Italy)*		Tasks 2, 3
6	*Piccoli S.r.l. (Noale (VE), Italy)*		Tasks 2, 3
7	Helmholtz-Zentrum Berlin (Berlin, Germany)	Task 6	Tasks 1 and **6**
8	RTU (Riga, Latvia)	Task 5	Task **5**
9	University Siegen, (Siegen, Germany)		Tasks 2, 3, 6
10	UKRI/STFC/ASTeC (Daresbury, UK)	WP, Tasks 1 and 3	Tasks 1, 2, **3**, 5, 6
11	*Lancaster University (Lancaster, UK)*		Tasks 1 - 3
12	*Jlab (Newport News, Virginia, USA)*		Tasks 1, 2
13	*PTI (Physics-Polytechnic Institute, Minsk, Belarus)*		Tasks 1, 2
14	*MEPHI (National Research Nuclear University, Moscow, Russia)*		Tasks 1 - 3
15	*Helmholtz-Zentrum Dresden-Rossendorf (Dresden, Germany)*		Tasks 1 – 3, 5

Accelerator R&D Roadmap - RF Panel -Thin films
Identified axis of R&D

1. Continue R&D niobium on copper
- Fabrication cost reduction
- Reaching same performances as bulk Nb (1,3-0,4 GHz, various shapes) on single cells, then on multi-cells

2. Intensify R&D of new superconductors on Cu
- Same performance (Q_0) as Nb @ 4,2 K instead of 2 K
- A15 compounds (Nb_3Sn, Nb_3Al, V_3Si) and MgB_2

3. Pursue multilayers (SIS structures)
- Reaching higher gradients (and Q_0 !)
- Going from sample to cavities

4. Intensify Cu cavity production and surface preparation.
- No welding, smooth surfaces, possible diffusion barriers
- Large series production

5. Develop 3D printing and/or innovative cooling techniques.
- Cryocooling, inbuilt circulation

6. Infrastructures and Manpower
- Dedicated characterization set-ups
- Dedicated thin film infrastructures

Other projects with similar strategy

Europe
- **Basic R&D in numerous SRF labs**
- **IFAST WP 9 thin films => 2025**
  - Task 9.1: strategy
  - All European partners except CERN and DESY
  - CERN, DESY, and JALB invited to participate in the strategy meetings

USA
- **Snow mass White Papers => next 10Y**
  - Last edition: 2021
  - 1 white paper on thin films, (AF7 Accelerator Technology R&D)
  - Ifast participants participated to the writing

Internat'l
- **TF SRF Workshops 2022 and 2024**
- **TTC-Meetings-thin films: ~ 2-3/year**
  - Bringing the community together

Contour should keep the same…
… but one need to accelerate/fill the holes

		Roadmap			Implementation Phase	
		Minimal	Nominal	Aspirational	2023 survey	Mean value/ lab
WG2 Thin films	Cost per year (k€)	2 400	4 000	12 000	**871**	167
	FTE per year	10	23	39	28	4,7

< ½ minimal
< ¼ nominal

Additional resources will allow:

- To intensify R&D and accelerate the progress in a field
- Scale up of 3D printed cavities, surface state improvement on cavities, explore new 3D processes
- Procure new essential equipment or services

European blindspot ???

1-3: thin films on Cu, Multilayers

- 1- Fabrication cost reduction for cavity fabrication with frequencies < 700 MHz.
  - Accelerate prototypes testing @ $\neq \omega$ with the new techniques (mainly substrates/task 4)
- 2- Intensify R&D of new superconductors on Cu - 4.2 K operational cost saving:
  - Nb_3Sn (but not limited to)
    - Explore other fabrication methods (electrodeposition, ALD, bronze route => easy industrialization)
    - Overcome composition issues (try other A 15 less sensitive, e.g. V_3Si)
    - Explore possible issues (tunability, flux trapping…) *(limited work taken in charge by ISAS, must be extended to all explored routes)*
  - MgB_2
    - Launch an effective activity in Europe (∃ in USA, China , Japan)/ find synergies with SC electronics ?
- 3- Pursue Multilayers - Push for high gradient:
  - Part of it depends on 2-
  - Several labs @ the prototype phase, main issue is
    - Technical support, access to Cleanroom + RF test (often an internal money question)
    - Extended material characterization

In brief it needs mostly money + students

4-6: thin films on Cu, Multilayers

- 4- Intensify Cu cavity production and surface preparation:
  - Fabrication:
    - High TRL, Accelerate industrialization
  - Surface preparation:
    - Paramount, should also explore AM surface preparation
- 5- Develop 3D printing and Innovative cooling techniques:
  - Premises only!
    - Explore various fabrication methods
    - Explore different cooling scenarios
    - Explore possible issues (tunability, flux trapping…) *(limited work taken in charge by ISAS, must be extended to all explored routes)*
- 6- Infrastructures and manpower - High throughput testing:
  - Budgets to help R&D to access clean rooms + RF test
  - Opening new dedicated infrastructure at CERN to other European collaborators ?

Dreamlist* per team:

Institution	Needed Workforce [FTE]	Needed infrastructures (cost per year)
CEA	8-9 FTE Half of it: tec. support	New furnace for pre- and post- ALD processing New ALD deposition set-up for multicells (~500 k€) financial support for (10-15) RF tests and characterization subcontracts (250-300 k€)
CERN	7 FTE	using existing equipment
Hamburg U.	7 FTE	Ramping up present activities (ALD, QPR set-ups) Substrates (samples, cavities) PCTS / CryoSTM is needed to locally measure gap / Tc ~150 k€ ?
HZB	1 FTE	100 k€
HZDR	3 FTE	Flash lamp annealing of cavities + caracterisation, faster turn-over 100 k€
INFN	8 FTE	Ramping up present activities 200 k€
IEE	0.5-1 FTE	using existing equipment
RTU	1-2 FTE	Ramping up present activities, new laser with higher power 200 k€
STFC/CI	14 FTE	Full power and low power testing facilitues for 1.3 GHz cavities 200 k€
USI	12 FTE	Process development (hollow cathode) in order to realize coating of cavities Characterization and RF tests 200 k€

* in addition to present funding, student non included

Roadmap for future R&D

- Road map not far from being clearly identified by the present European actors
  - Collaboration within Europe is active
  - International Collaborations are also active
- Worldwide the landscape is the same:
  - Small teams with limited budget, limited technical support, limited access to RF tests
  - Project always come first, hence R&D is very slow
- Bulk Nb technology has reached its theoretical limits in terms of performance
- Difficult to build ambitious/ advanced machine with the same Nb technology: costs increase with:
  - Increased technological demand (higher energy, higher power machines…)
  - Increasing energy costs
  - Increasing He costs
- Thin films:
  - No European program after 2025 (except ISAS, w. limited participation)
  - Most lab have limited R&D resources (sometimes, individual countries too ☹)

We need to change paradigm !!!

Finance and staff

	Staff	PhD students	Finance per year	
Present	30	9	871 k€	
Ideal	60	18	2100 k€	

Additional resources will allow:

- To intensify R&D and accelerate the progress in a field
  - With more staff, postdocs, PhD students
  - More SC materials to explore
  - More tests of TF coated RF cavity, as well as QPR, choke cavity and split cavity
    - To operate existing facilities, which can be used in present due to lack of staff
    - To cover LHe, consumables and electricity costs
  - To intensity laser and FLA annealing of TF on copper samples and cavities
- Scale up of 3D printed cavities, surface state improvement on cavities, explore new 3D processes
- Procure new essential equipment or services
  - For newly built or upgraded existing facilities
  - More copper cavities and their polishing
  - More deposition targets
  - More surface/material characterisation and SC property measurements
  - To enable clean room access
  - New furnace + new ALD coating set-up (to progress to larger cavities and multicell cavities)
  - Quicker progress to multicell coating and testing