Microscopic Examination and Elemental Analysis of Surface Defects in LEP Superconducting Cavities

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Abstract

A diagnostic tool, based on a computer controlled surface analysis instrument, incorporating Secondary Electron Imaging, static Auger Electron Spectroscopy and Scanning Auger Mapping has been designed and built at CERN to characterize the inner surface of LEP superconducting cavities with provide unsatisfactory radio-frequency performance. The experimental results obtained to date are reported and discussed.

1. Introduction

The industrial production of the 224 superconducting 352 MHz four-cell cavities required for the Large Electron Positron (LEP) collider energy upgrade [1, 2], is in progress. The majority (about 200) of these cavities are made of copper, internally coated with a 1.5 µm thick niobium film, deposited by magnetron sputtering [3]. These niobium coated copper cavities (Nb/Cu) provide several advantages compared to bulk niobium cavities, namely with respect to thermal stability, higher quality factor, cost, insensitivity to trapped earth magnetic field which deteriorates the quality factor.

Contamination and surface defects which may be produced during the manufacturing process have severe detrimental effects on the radio-frequency (RF) performance of the cavities [4] because of enhanced power absorption and/or electron field emission.

In order to improve the cavity quality, it is essential to trace the origin of the surface defects which are usually detected by temperature mapping measurements during the RF acceptance testing of cavities at CERN. For this purpose a dedicated computer controlled surface analysis instrument, incorporating Secondary Electron Imaging, static Auger Electron Spectroscopy (AES) and Scanning Auger Mapping (SAM), has been designed and built at CERN. This new diagnostic tool, nicknamed "Strombinoscope", allows microscopic examination and elemental analysis of defects via an endoscopic inspection of cavities [5, 6].

In this paper, after a brief description of the instrumentation and inspection procedure, the most relevant results obtained to date are presented and discussed.

2. "Strombinoscope" instrument and experimental procedure

The general layout of the "Strombinoscope" is presented in Fig. 1. The heart of the instrument is the AES and SAM analysis system which consists of a commercial single pass cylindrical mirror analyser (CMA) with coaxial electron gun. The Secondary Electron Detector (SED) consists of a channeltron multiplier and related electronics. The CMA and SED, which have been significantly modified, are fitted via an appropriate flange to a 3-axis robot arm [7]. This computer controlled robot arm positions the analytical head inside the cavity at a safety distance of the order of 10 mm from the cavity wall. The fine positioning is adjusted using specular electron beam calibration.

The ultra high vacuum system is schematically presented in Fig. 2. The lower part of the instrument is bakeable up to 120°C, and the cavity up to 200°C. The base pressure of the device after bakeout is of the order of 5.0×10^{-10} Torr.

The endoscopic inspection is usually performed using a primary electron beam energy of 3 keV, at a pressure below 2.0×10^{-8} Torr. The lateral resolution is about 10 µm at 3 keV and the analyser relative energy resolution $\Delta E/E$ is fixed to 1.2%. The data acquisition system is controlled via standard software.

About 160 Nb/Cu cavities have been accepted by CERN to date (September 1995). The cavities which do not fulfil CERN specifications are usually inspected by means of a video camera set-up on an optical inspection bench [8], which provides sufficient information on the morphology of large defects. In some cases, however, further investigations are required to characterize the surface defects. To date this additional inspection has been carried out on six Nb/Cu cavities by means of the "Strombinoscope".

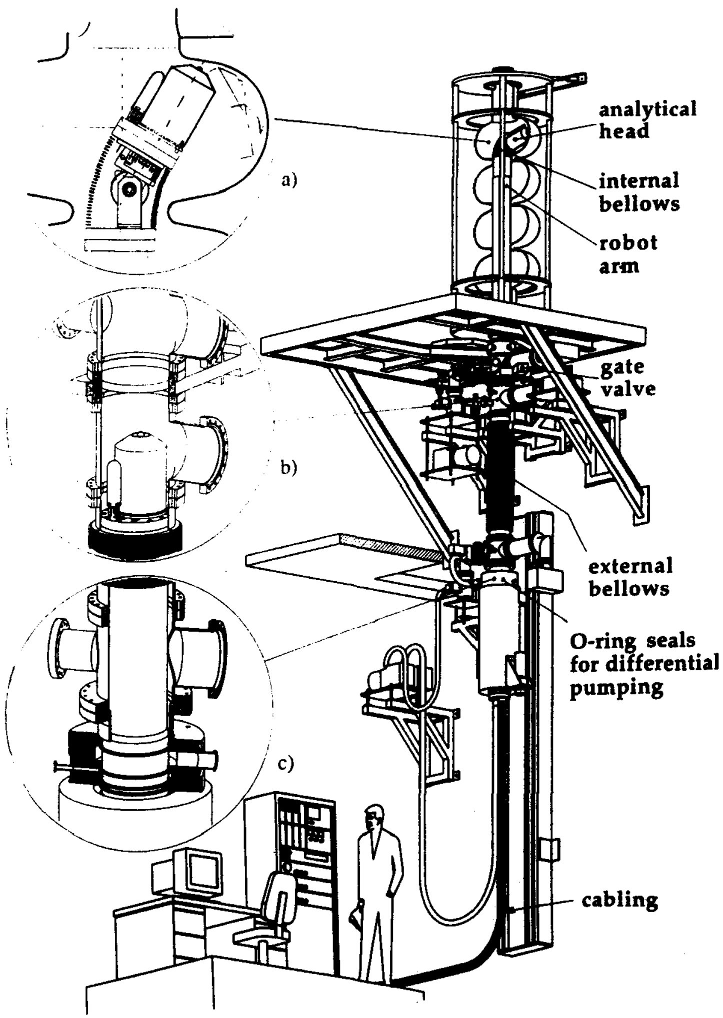

Fig 1: General layout of the "Strombinoscope" instrument.
View of the Cylindrical Mirror Analyser (CMA) and the Secondary Electron Detector (SED), fitted to the robot arm, inside a cell of a LEP superconducting cavity (detail a, cables are not shown). DN200 gate valve separating the two systems (detail b) and Φ rotation system (detail c).

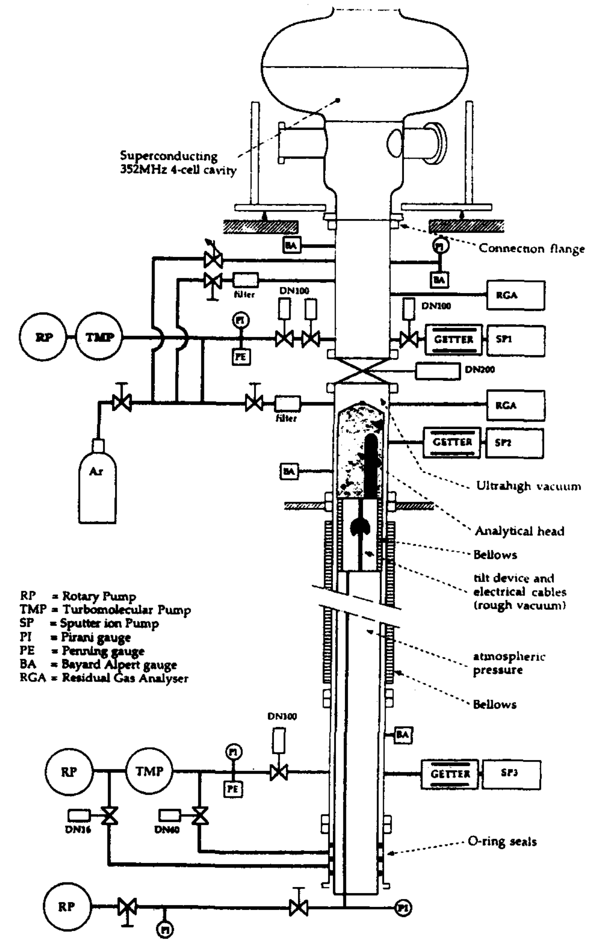

Fig 2: Schematics of the ultra high vacuum system.

3. Results and discussion

The defect-free areas of the Nb film are oxidised (Nb_2O_5) [9] and in general show very low carbon contamination. The majority of the defects which have been analysed, consist of regions where the Nb coating is missing; the substrate Cu surface is visible, oxidized and highly contaminated with C (sometimes Ni and Fe are also detected). The linear dimensions of the exposed Cu area range typically from 50 µm to 1 mm.

A preliminary classification of the defects encountered to date is presented in table 1.

NUMBER OF INSPECTED CAVITIES	: 6
TOTAL AREA ANALYSED (estimate)	: 0.5 to 1 m^2
NUMBER OF DEFECTS FOUND AND ANALYSED	: 30
TYPES OF DEFECT :	
- Bare copper (in 3 cases with Ni, Fe contamination)	found 14 times
- Carbon granules	found 3 times
- "Stains" with Cu visible without complete peel-off of the Nb film	found 3 times
- Dust particles	found ~ 10 times
- Etching pits (usually found isolated; in one case, found in large concentrations)	found more than 50 times

Table 1 - Summary of the results of cavity inspection

The most characteristic defects (etching pits, C granules, stains) are illustrated in Fig. 3. In general, it has been possible to correlate the total surface area of these normal conducting defects with the unsatisfactory RF performance of the corresponding cavity.

4. Summary

Surface defects, detected and localized with a resolution of 10 mm by temperature mapping, have been analysed directly inside LEP superconducting cavities using Secondary Electron Imaging and AES techniques with a lateral resolution better than 10 µm.

The endoscopic inspection of LEP cavities confirms that the major difficulty in the production of Nb coated Cu cavities is the preparation and the handling of the copper surface prior to Nb sputter-coating.

The "Strombinoscope" instrument could also provide invaluable information on the nature of electron field emitters which develop during the real life cavity operation. We intend to invest some effort on this subject in the near future.

References

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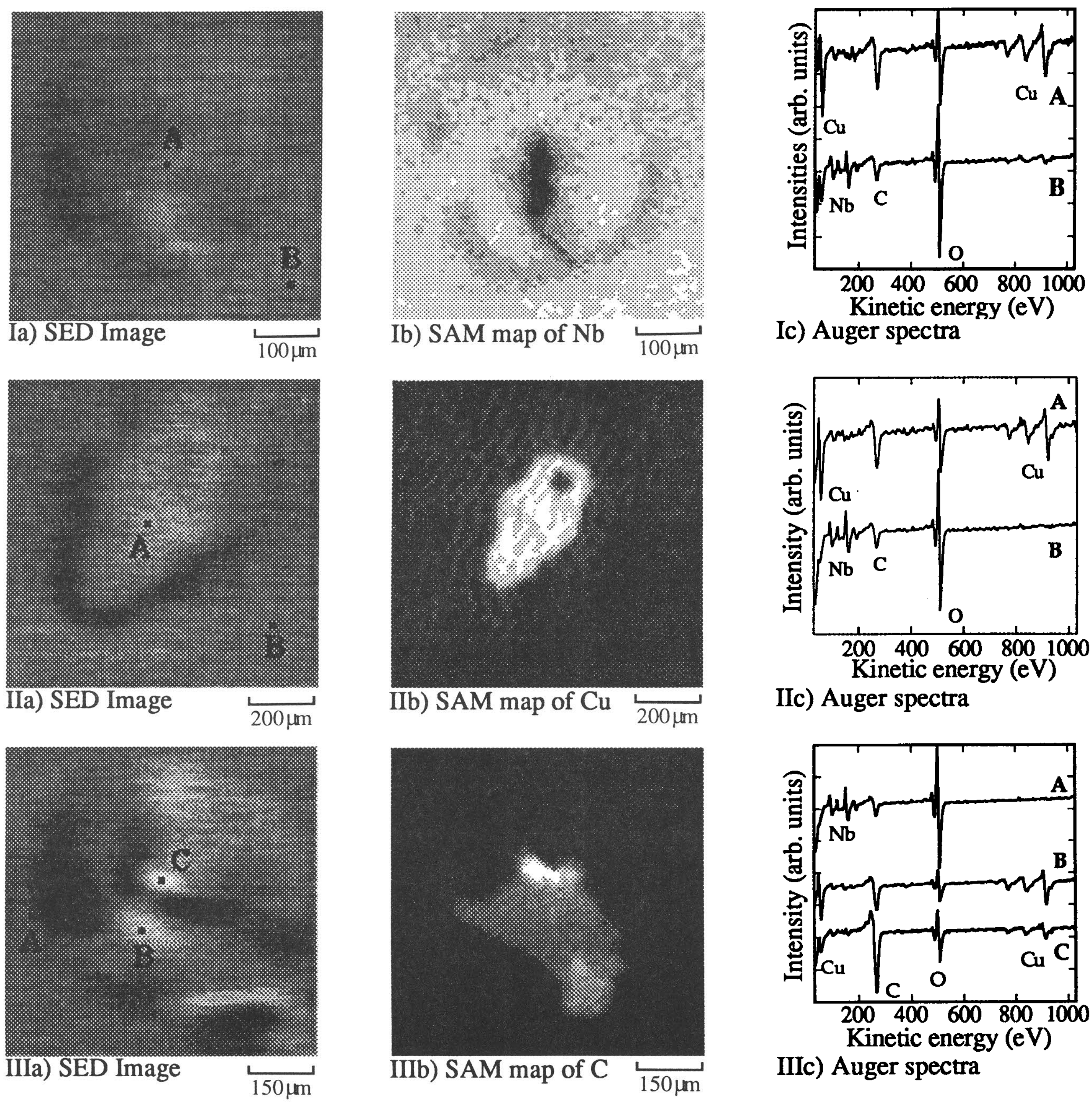

Fig. 3: Examples of typical defects in Nb/Cu LEP superconducting cavities:
(In the SAM maps, lighter areas correspond to higher concentration of the analysed element)

I) "Blister"; the film is no longer in contact with the substrate and the Cu is visible at central point.

II) One of the largest defects detected with Nb-film peel-off.

III) Film peel-off with C granules.

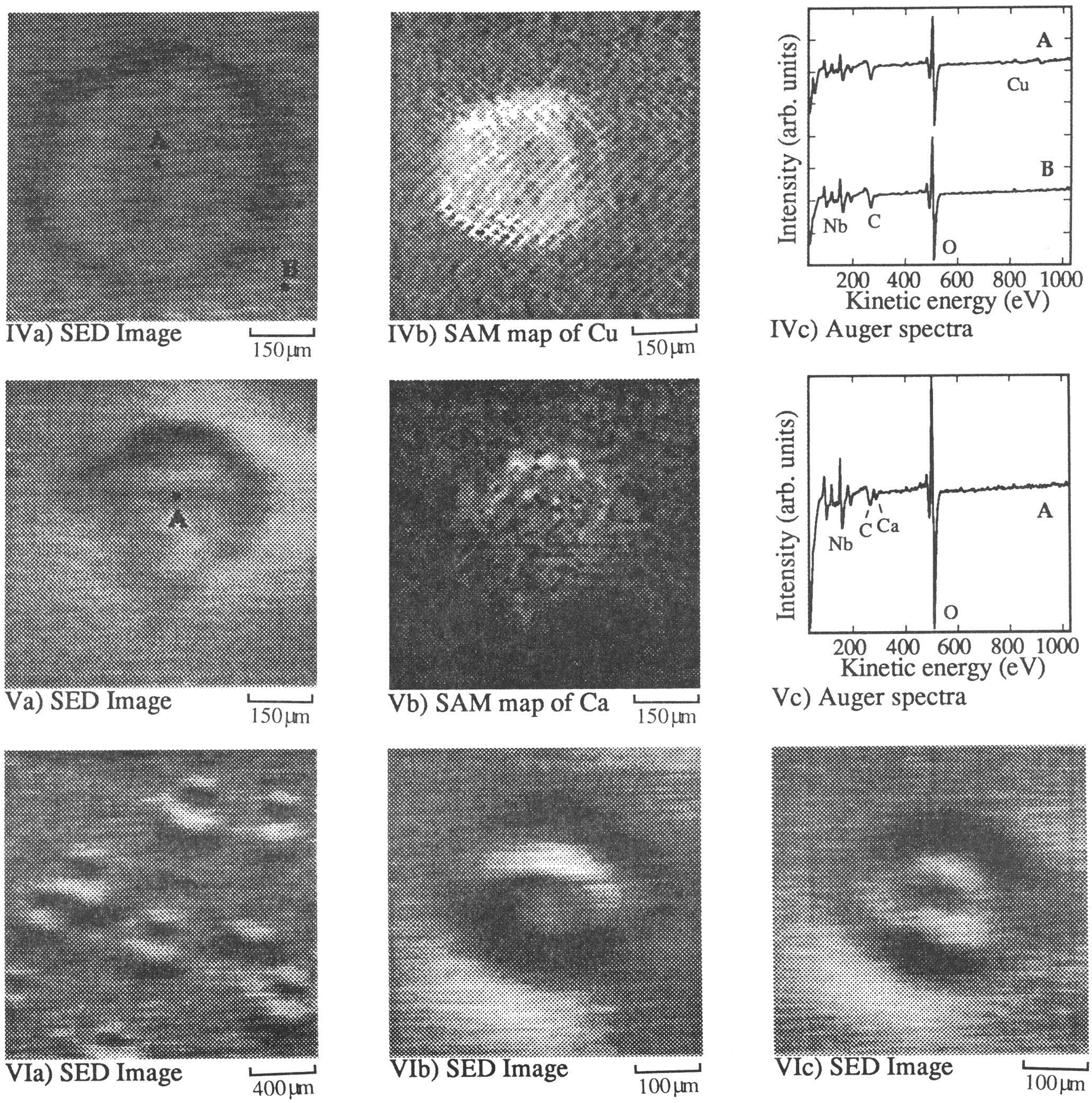

Fig. 3 (continued):

IV) "Stain"; the Nb film is still present but some Cu is detected.

V) Surface defect with Ca contamination.

VI) "Etching pits", covered with the Nb film.