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Ion beams and synchrotron light in perspective

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This work is devoted to reflecting on the very different features and dynamics of ion beam and synchrotron facilities and user communities. Whereas both suites of techniques are highly interdisciplinary and offer good science opportunities to similar fields of science, traditionally the two communities have lived in separate worlds, with scarce knowledge of one another and very limited collaboration.

Keywords: Synchrotron light and ion beams; diffraction; photon spectroscopies.

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1. Introduction

This work is devoted to reflecting on the very different features and dynamics of ion beam and synchrotron facilities and user communities. Whereas both suites of techniques are highly interdisciplinary and offer good science opportunities to similar fields of science, traditionally the two communities have lived in separate worlds, with scarce knowledge of one another and very limited collaboration.

The paper is organized as follows: Section 2 makes a very general overview of some of the most relevant techniques based on synchrotron light and ion beams, focusing on differences and complementarity; Section 3 takes as an example two Spanish facilities well-known to the author, in order to illustrate similarities and differences; Section 4 reviews a few scientific cases where complementarity between synchrotron light and ion beams plays or may play a relevant role; finally Section 5 summarizes the main findings of the paper and reflects on possible future actions where joint work may lead to interesting results. All these sections will be covered very briefly, giving indications of the main relevant aspects. A more exhaustive and detailed analysis is left to a future work, to be published elsewhere.

2. Synchrotron and ion beam techniques

Many different techniques have been developed based on synchrotron light during the last decades. If one adopts a very global and non-exhaustive view, some of the main ones may be grouped and summarized as follows:

- Diffraction: long-range atomic structure, samples may be single crystals of policrystals, structured is averaged along depth, 2D resolution is possible.
- Photon spectroscopies: chemical specificity, local structure, dichroism is possible, average measurement along depth, 2D resolution is possible.
- Electron photoemission spectroscopies: surface selective, chemical specificity, imaging possible, dichroism possible.
- Imaging/tomography: direct visualization of sample (direct detection or algorithm-driven from reciprocal space).

On the other hand these techniques are based on very large and powerful facilities, serving a large and well-structured international user community, with beamlines incorporating many in-situ instruments complementary to synchrotron light itself and with the possibility of performing time-resolved measurements down to the ps range (fs for free electron lasers).

Ion beam techniques, again with a broad and non-exhaustive view, may be classified as follows:

- Analysis based on nuclear interactions, ion in/ion out: elemental depth profiling, isotope resolution possible, 2D resolution possible.
- Analysis based on atomic/nuclear interaction (ion in/photon out): trace element detection, average along depth, 2D resolution possible.
- Channeling configuration: structural/defect information (single crystals only).
- Modification: implantation or damage engineering, very wide possibilities for materials processing.

These techniques are generally deployed at medium size or small facilities, with a limited but very dedicated user community, incorporating only in few cases complementary in-situ tools, and very rarely doing time-resolved science.

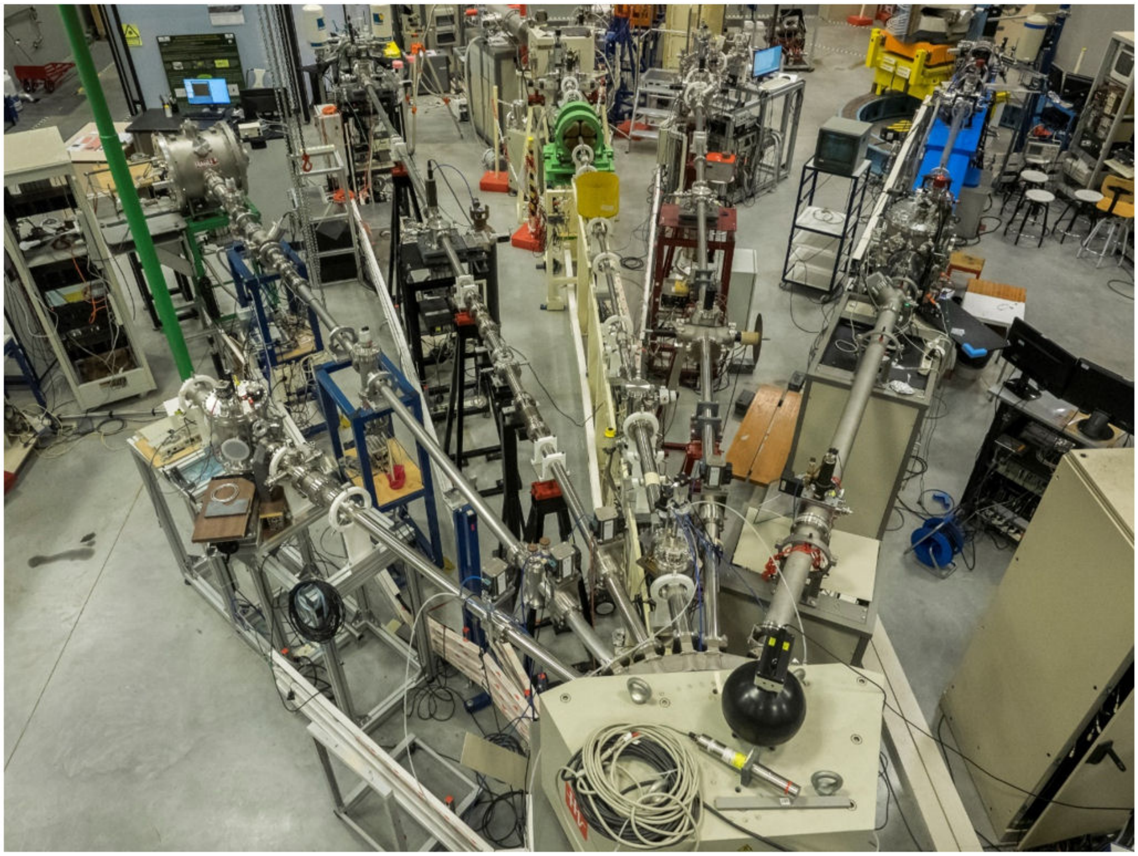

FIGURE 1. CMAM beamlines, emerging from the switching magnet at the output of the ion accelerator.

In summary, synchrotron techniques provide extremely rich and diverse tools to understand matter at the nano and mesoscale. This implies a large investment effort and the size of the facilities makes them, as a side-effect, very powerful science hubs, beyond the base contribution of the techniques offered. Ion-based techniques are an excellent complement to synchrotron ones when depth profiling or trace element detection (possibly with 2D resolution) plays a relevant role. In addition ions may be used to modify materials in unique ways and to understand how these damage processes, crucial in areas such as fusion energy, take place and may be managed or mitigated. Ion facilities, being small or medium size, provide a very natural scientific landscape complement to larger synchrotrons in a country. However this complementarity is not very frequently exploited in practice.

3. Synchrotron and ion beam facilities: ALBA and CMAM

ALBA and CMAM are respectively synchrotron and ion beam facilities located in Spain. They were both built during the 2000 decade, CMAM starting a few years before ALBA. Their relative size may be exemplified by the initial investment (at the level of 200 ME for ALBA and 10 ME for CMAM), by the yearly running cost (about 10% of the initial investment in both cases), or by scientific production (above 200 publications per year at ALBA, in the range 20-30 depending on the year at CMAM). Further details may be found in Ref. [1-4] for ALBA and [5-6] for CMAM. Fig. 1 presents a panoramic view of the CMAM beamlines at the output of the ion accelerator.

4. Scientific case examples: synergies

There are many cases in which ion beams and synchrotron light may be used in a complementary way. In this section a few cases are illustrated as an example, either based on published experiments, ongoing work or just ideas for the future. Complementarity may arise from different combinations: analysis techniques which complement one another for characterization of materials, studying the modification of materials by ion beam with subsequent analysis by synchrotron techniques, or even processing of materials with ions for future applications in instruments to be used at synchrotrons.

In the first case we may cite [7-8], where XANES, XRD (synchrotron) and RBS (ions) were used in a complementary way to understand better the preparation process of Cr or Ti oxide films. Here XANES was used to look at the valence states of Cr or Ti averaging along the sample depth, whereas RBS was used to verify the Cr-O or Ti-O stoichiometry as

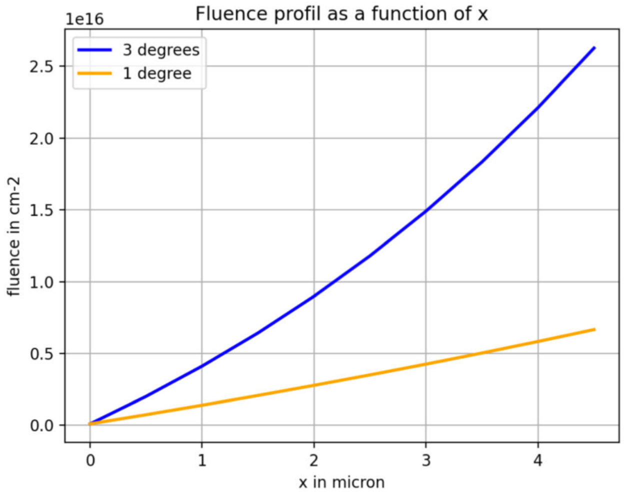

FIGURE 2. Calculated fluence profile to obtain 200 line/mm blazed gratings with two different blaze angles, by irradiating synthetic diamond with a 9 MeV C ion beam. M. Martin is kindly acknowledged for the preparation of this figure.

a function of depth. XRD was used in both cases to check crystallinity.

Also in Ref. [9] PIXE (ions) and XRD (synchrotron) were used to characterize samples which emulate the historical features of Co and As based pigments for ceramic archaeological pieces. In situ temperature cycling of the samples while doing XRD characterization was used to emulate the ancient manufacturing processes and shed light on the composition differences observed in objects from different periods of the 15^{th}-16^{th} century.

A collaboration has been recently started between UNAM, U. of Guanajuato and CMAM, with the aim of characterizing biomorphs with 2D-resolved, micron resolution PIXE composition maps, and thus understanding better the features of these tiny objects, which have inorganic nature but emulate biological morphologies. Eventually this collaboration could be futher developed by doing micro-XRD maps, in order to have 2D-resolved information on local structure, with the same spatial resolution as for the composition maps to be obtained by PIXE.

An ongoing collaboration between CMAM and ALBA is exploring the possibility of manufacturing X-ray gratings by using ion beam lithography [10-11]. A particularly challenging material, synthetic diamond, is being used as a possible future option for ultra-high heat load applications in X-ray science. Figure 2 shows a calculation on how two given grating profiles typical for soft X-ray monochromatization (blaze angles indicated in the figure) could be manufactured by depositing a given fluence pattern of 9 MeV C ions on synthetic diamond (unpublished). Proof-of-concept experiments have already been performed successfully at CMAM to demonstrate this procedure, yet to be published.

5. Conclusions and outlook

Synchrotron and ion beam facilities and user communities are very different and have historically held very limited collaboration. However the techniques are clearly complementary in a number of ways. This paper aims at illustrating and exemplifying such possible collaborations. Some of the directions which may help exploit the potential synergies are: coordination at the facility level, as in the recently launched ARIE initiative [12]; joint user community activities; and perhaps collaboration in data policies. On may also expect that progress in both synchrotron and ion beam techniques may unlock in the future some scientific opportunities which are today out of reach.

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12. ARIE stands for Analytical Research Infrastructures in Europe, arie-eu.org.