The importance of the GANIL facilities for non-nuclear and cross-disciplinary sciences

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We, the senior scientists of the Materials Research Department at GSI Helmholtzzentrum (Darmstadt, Germany) would like to share our views about the perspectives and importance of the non-nuclear and cross-disciplinary research at the GANIL accelerator facilities (GANIL/CIMAP).

High energy ions provide excellent and very broad experimental research capabilities for many disciplines including material science, solid state physics, surface science, crystallography, mineralogy, geosciences, nanotechnology, space science, biology and many others. The research activities in these areas are extremely diverse and are subject to rapid scientific developments. This is particularly true for new opportunities in the field of ion-beam based applications.

The GANIL/CIMAP and the Materials Research (MAT) department of GSI share the longtime experience in operating dedicated beamlines for research projects with swift heavy ions in material science and other cross-interdisciplinary fields. For more than 30 years both groups have been in close contact and have been collaborating on various topics mainly in the energy regime of MeV-GeV. This has resulted, e.g., in about 70 joint publications and many co-organized conferences, workshops and summer schools.

At present, access to beamlines dedicated to material science in the high-energy range (MeV-GeV) exists worldwide only at very few accelerators. Besides GSI, this includes IMP/CAS in Lanzhou and JINR in Dubna, but they are limited in beam energies and/or intensities. Other large-scale facilities such as Riken, MSU, and BNL could in principle partly provide high-energy beams, but they do not have onsite expertise and infrastructure required for material science. New facilities currently under construction such as NICA/Dubna in Russia and RAON in Korea seem to plan activities in material science and biophysics, but so far have little/no experience.

Peculiarities of the GANIL/CIMAP facilities

The uniqueness of the GANIL/CIMAP facilities consists in the combination of the high- and medium-energy beamlines HE and SME and the low-energy beamlines IRRSUD and ARIBE. It should be emphasized that this broad platform goes far beyond any accelerators or implanters available at universities and in the semiconductor industry. The possibilities with these four facilities are excellent, because (i) the low energy beamlines can partly be operated in parallel, giving flexibility and enhancing the overall access to beam; (ii) the users can select the most suitable energy regime (left and right of the Bragg maximum), ion range and charge state according to their specific project, and (iii) the sophisticated equipment installed at the different beamlines allows the users to perform measurements directly on-line and/or in-situ, which is not possible at other facilities.

An extremely important prerequisite for this success is the excellent user support provided by the CIMAP/CIRIL team. It is also essential to mention that this support is strongly correlated with the expertise based on the in-house research of the group. The CIMAP/GANIL team makes regular and high impact contributions to the advancement of the research field. Their expertise and leading contributions have excellent reputation worldwide.

Experiments performed at the different GANIL/CIMAP facilities offer specific advantages:

- All ion species from carbon up to uranium are available; by the combination of the two cyclotrons, a broad variety of ion energy loss values is accessible.
- Beams from low to extremely high energies (some keV/u – 100 MeV/u) are available comprising more than 6 orders of magnitude. The high energies correspond to extreme ion ranges enabling the irradiation of macroscopic thick samples.
- In-situ and online analysis is possible due to sophisticated equipment attached to the beamlines (e.g., x-ray diffraction, absorption spectroscopy, heating and cooling stage, etc.).

Fields of interest for non-nuclear physics and cross-disciplinary research at GANIL

Based on the high-energy irradiation experiments during the last thirty years, scientific knowledge and fundamental understanding of ion-matter interaction processes have achieved great advances and GANIL/CIMAP has significantly contributed to this success.

The specific properties of swift heavy ions are that they deposit enormous energy densities into solids, driving the local atomic structure far from equilibrium. This leads to rapid phase transitions and complex structural modifications including transient and long-lasting radiation damage. Details of these processes depend strongly on thermal, electronic and structural properties of a given material and are far from fully understood.

Research at the unique GANIL/CIMAP facilities will continue to provide important insights into these fundamental questions. The basic understanding is also an essential prerequisite for the starting point and success of a large variety of application-oriented developments.

The number of interesting topics for future research at GANIL/CIMAP is too large to be listed in this letter, however we would like to mention several fields of important and exciting research:

<u>Tailoring materials properties</u>

By the adjustment of suitable beam parameters, structural, optical, electronic, thermal and other material properties can be tailored by the controlled implementation of defects such as single point defects, multi-atomic vacancies, extended defect or small defect clusters. The large energy range available at GANIL/CIMAP is perfectly suited to clarify specific contributions of the electronic and nuclear energy loss.

<u>Radiation hardness</u>

The radiation hardness and reliability of materials is important for devices that need to operate in extreme dose environments such as nuclear materials or beam-intercepting components in future high-power accelerators (Spiral-2, FAIR, EES, CERN). Understanding radiation-induced damage processes is a key prerequisite for safe operation and reliable lifetime estimates.

<u>Simulating of cosmic radiation</u>

Irradiation experiments with energetic ion beams simulate the effects of cosmic rays in the laboratory. This possibility is of great interest to test electronic devices for space applications.

Important contributions can be made to improve the understanding of radiation effects on cosmic dust grains and the formation, radioresistance and survival probability of complex organic molecules (e.g. nucleobases) in interstellar media.

Nanotechnology

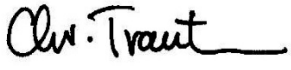
Swift heavy ions are of particular interest for numerous applications in nanotechnology including single-pore membranes for sensor technology as well as etched ion-track membranes as filters or templates for the synthesis of nanowires.

Future evolution at GANIL/CIMAP

With regard to the future development of non-nuclear research activities at GANIL/CIMAP, we strongly recommend the following strategies:

- Continuing to operate this unique user platform is extremely important to the national and international science community and reinforces the current worldwide leadership of the European facilities.
- In order to optimize research programs, the community needs beam access on a regular base with several runs per year.
- Taking into account the large number of users and the regular overbooking of GANIL/CIMAP as well as of GSI/MAT by a factor of two or more clearly reflect the needs of the national and international users. The GSI facility alone will not be able to provide sufficient beamtime for this large user community.
- The sophisticated on-line and in-situ instrumentation needs to be constantly developed to stay at the forefront of science.
- It is important to foster strategic international cooperation with other ion beam laboratories and to promote new scientific directions in application-oriented research.
- It would be very beneficial to enhance connections with universities and offer special student programs. Education and training is essential for the next generation of experts in the field of radiation physics and material science.

Finally, we would like to conclude our letter by strongly emphasizing again that the GANIL/CIMAP facilities are unique in terms of beam parameters, instrumentation and expertise of the scientific staff. The facility is extremely important for our community now and in the future.



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