IFAST IIF Proposal

Graphenic foil stripper for high intensity particle beams

- GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt Germany - Lead Organization /IFAST member
- University of Münster, Germany- Participant Organization/IFAST member
- KETEK GmbH, Munich, Germany- Industrial partner Organization
- Department of Material Science and Enginnering, KAIST (Korea Advanced Institute of Science and Technology),

GSI Helmholtzzentrum für Schwerionenforschung

WWU MÜNSTER

KETEK

Soft Nanomaterials Lab.
Department of Materials Science and Engineering

iFAST

Marilena Tomut- GSI

Background and aim

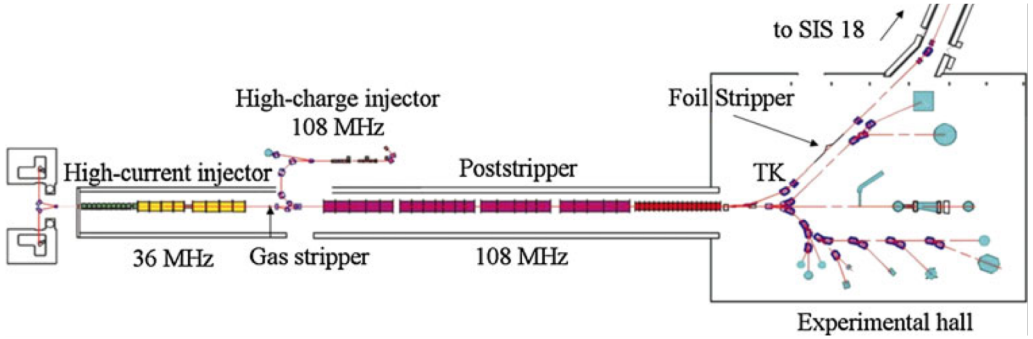
- *Aim of the project:*
  to provide the accelerator community a new stripper foil solution based on graphenic membranes with extended lifetime in high beam intensity applications

- *Context:*
  - solid strippers have the advantage of producing a higher average positive charge than gas based ones.
  - The gain in the charge state produced at the stripper could reduce significantly the expenses in accelerating stages needed to obtain the required final energy.
  - Conventional foil strippers for tandems, linear accelerators and cyclotrons must be very thin to reduce energy loss and improve energy definition – as a result, they can easily break during operation – limited lifetime

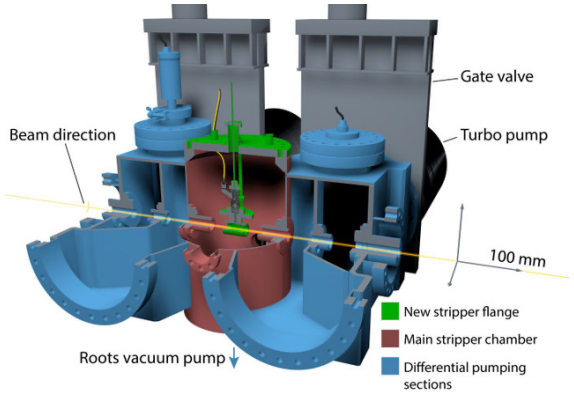
Case study – UNILAC accelerator at GSI as FAIR injector

- Stripper foil replacing the gas stripper at UNILAC, GSI- opportunity to deliver high intensity beams at higher energies and to investigate space charge effects

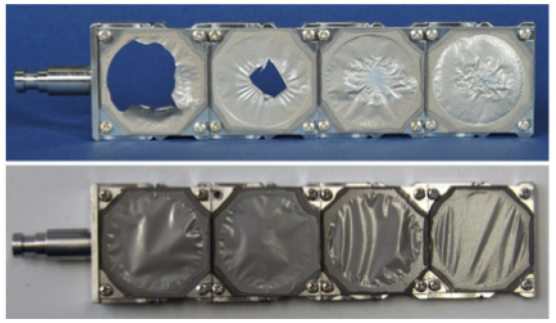
- Machine experiments with solid stripping at at 1.4 MeV/u were performed to investigate the capabilities accelerating highly charged high current uranium beams in the poststripper final UNILAC-beam energy.



The GSI-UNILAC with the gas stripper behind high current injector and the foil stripper at the transfer channel (TK)



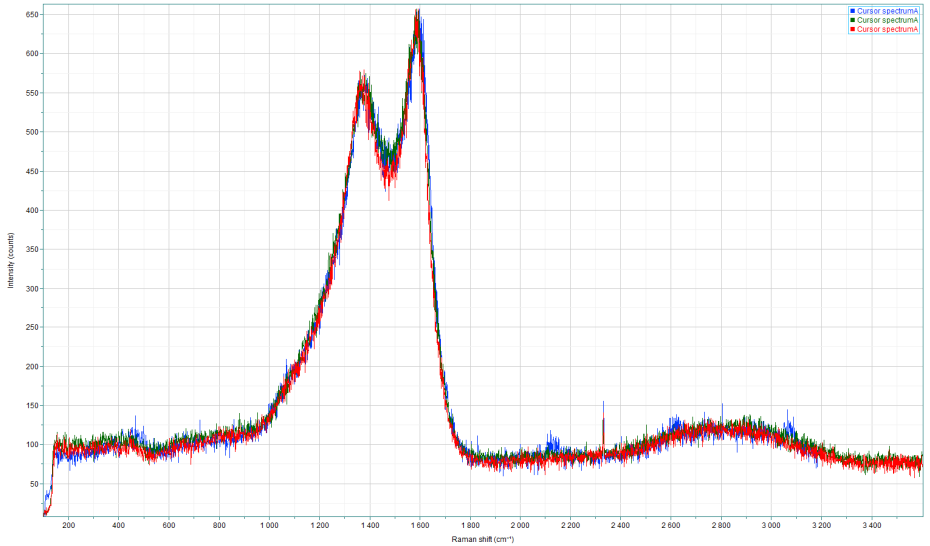
UNILAC gas stripper-U 28+



AC foil stripper - U 39+

Graphenic membrane vs. carbon foils

- The extension of stripper foil lifetime is possible due to very good thermal conductivity and mechanical strength of graphenic membranes in comparison with other carbon foils used for charge stripping in particle accelerators (amorphous carbon, DLC)
- The structural changes due to radiation damage and temperature increase due beam heating are mitigated by the special structure and properties of the used graphenic foils. Preliminary studies show that the starting structure of the foil is similar to the one achieved after high dose heavy ion irradiation of graphitic materials, mitigating the radiation damage effects in the material.



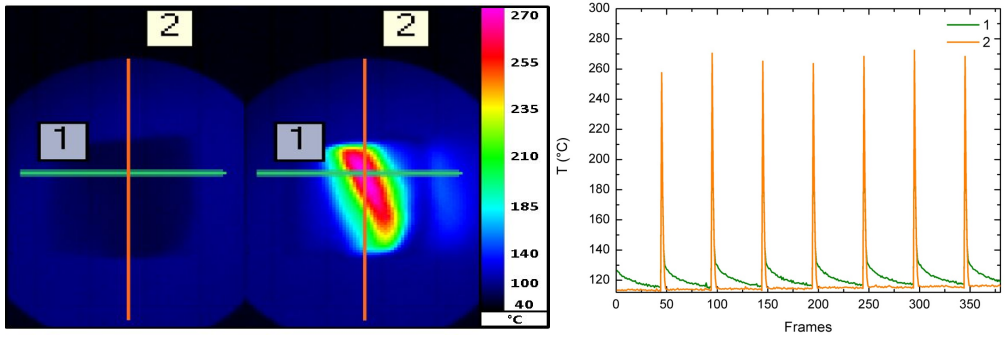
Raman spectra of pristine and high dose irradiated graphenic foils, showing minimal structural changes induced by irradiation:

Blue - pristine sample
Green - irradiated at GSI, 5E13 Au ions/ cm^2, 4.8 MeV/u
Blue -irradiated at RIKEN, 1.5e16 Ne ions/cm^2

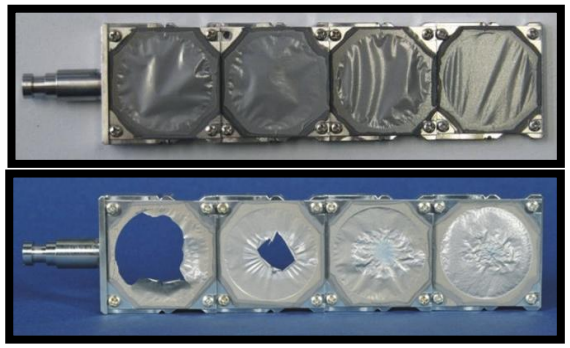
Technical overview

- *State of the art; proof of concept:*

  Solid membranes and gas jets solutions are used in accelerators to strip and further accelerate ions. For gas strippers the important drawback is the reduced charge state in comparison to solid stripper and the fact that, being windowless, leads to possible vacuum problems and more complex technological solutions. The use of solid stripper foils leads to important reductions in the investment for accelerating stages for injectors for high energy accelerators and to a reduction in energy consumption in operation of these accelerators. Preliminary tests by the project team on graphenic membranes show improved mechanical stability and radiation hardness in comparison to tests performed within a previous project funded by BMBF on current carbon foils for charge stripping applications produced in US, Europe and Japan.



Beam induced heating in a 20 µg/cm² amorphous carbon stripper foil induced by a high intensity, short pulse U beam at 4.8 MeV/u.

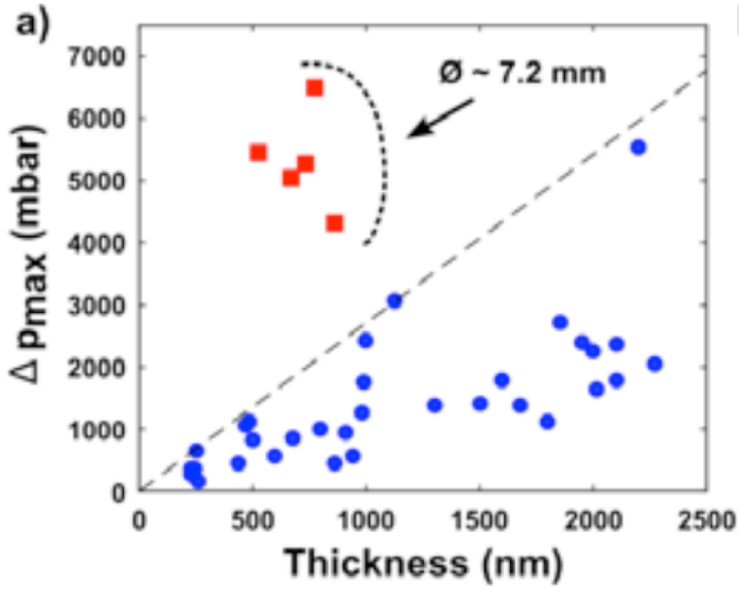


Failure of amorphous carbon stripper foils during operation at GSI UNILAC accelerator (W. Barth et al., LINAC2010, Tsukuba, Japan (2010)

Intact KETEK graphenic membrane exposed to high dose Au 4.8 MeV/u ions at UNILAC, GSI

Graphenic membrane vs. carbon foils

Material	Density	Thermal connductivity	Young's Modulus	UTS
AC	1.4 g/cm^3	0.2 W/mK	< 200 _GPa	?
DLC (Micromatter)	3.5 g/cm^3	0.2-3.5 W/mK	150-170 GPa	?
GC	2.2 g/cm^3	1500 W/mK	130 – 170 GPa	7 GPa



Huebner, S., Miyakawa, N., Pahlke, A., & Kreupl, F. (2016). ***Performance Improvement of Graphenic Carbon X-ray Transmission Windows****. MRS Advances, 1(20), 1441-1446. doi:10.1557/adv.2016.194*

Technical overview/2

- *The current status of the graphenic membranes production and testing:*

  - Our industrial partner, KETEK is currently producing graphene based membranes for application as X-ray transmission window for Silicon Drift Radiation Detectors based on two existing patents: US9514854B2 and DE102012107342B4.

  - First tests within IFAST for application of such graphenic foils in accelerator environment as beam windows, show a good robustness of the membranes exposed to high intensity heavy ion beams in some of the most demanding operational conditions as respect to radiation damage and beam induced thermo-mechanical effects

  - Current TRL status: at least TRL 4

Technical overview/3

- *Development plan related to applications as stripper foils:*
  - The lifetime of graphenic foils with areal density around 150 µg/cm2 will be tested with heavy ion beams in conditions relevant to charge stripping in linear accelerators at energies corresponding to maximum energy-loss and radiation damage.
  - Beam induced thermo-mechanical load will be inferred by infrared thermography and thermo-mechanical calculations
  - Measurements of stripper efficiency for graphenic foils at UNILAC accelerator at GSI
  - A market study for stripper foil applications will be made in parallel
  - The TRL 6 status could be reached for smaller, disc shaped supported graphenic stripper foils immediately after the end of the project; for custom shaped within 2 years after the end of the projector if the market gives a positive feed-back

Work Plan

- *Team and organizational expertise related to the project*
  - *GSI- accelerator technology, materials for high power accelerator, radiation damage, project management*
  - *WWU- materials characterization, high resolution electron microscopy, innovation, project management*
  - *KETEK – production of graphenic membranes, radiation detectors, radiation field, excellence in innovation –KETEK sensors were selected for Mars missions rovers "Curiosity" and "Perseverance"*
- *Project schedule and responsibilities among partners*

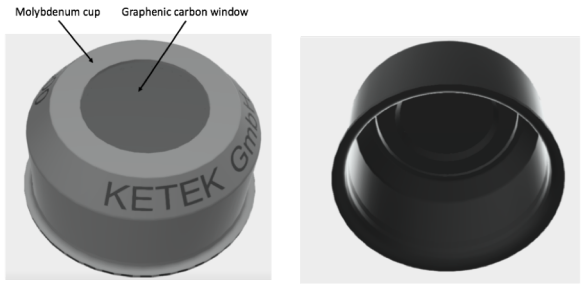
Task	2023				2024				2025
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
Production of graphenic membranes with different thickness and increased size (KETEK)			M1						
Lifetime testing in accelerator in relevant conditions for charge stripping applications (GSI, WWU)									
Characterization of stripping efficiency of graphenic membranes with different thicknesses (GSI, WWU)						M2			
Characterization of irradiated membranes (GSI, WWU)								M3	
Frame supported graphenic stripper foils with different thickness for accelerator environments (GSI, KETEK)									D

Risk analysis

	Potential Risk	Mitigation
1	Partners stepping back	A continuity plan will be adopted allowing the remaining partners to take up the work load of the leaving part.
2	Over-cost / over time	Project will be monitored and frequently assessed to avoid over-running's
4	Reduced beamtime for testing as effect of the current energy crisis	Tests are planned at the UNILAC accelerator at GSI. There is a high interest of the Japanese accelerator community for this development, additional beam time applications are possible in collaboration with RIKEN

Different geometries and thickness

- It has been proven on the laboratory scale that they can be achieved
- Ketek has a completely automatized/closed process for the production of X-ray detector housing with integrated graphenic window optimized for this application. They will produce only frame supported foils with different thickness and slightly larger diameters for this application

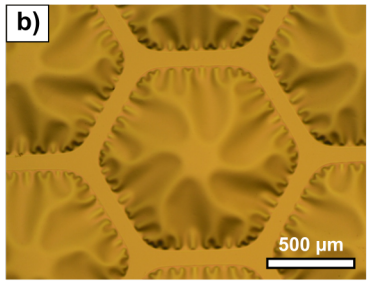


S. Hübner, PhD thesis, TU Münschenn, 2016

Intrinsic wrinkles help accommodate stress

Large Si wafer with CVD deposited graphenic layer

Etched GC membranes on frames



Arbitrary shapes through pre-structured Si substrates

Applications and impact

- In the accelerator sector, novel materials for solid stripper foils with improved resistance to intense heavy ion beams contribute essentially to increasing the energy efficiency by reducing the number of accelerating units requested to achieve a certain energy of the accelerated particle beams [1,2] .
- Accelerator for applications:
  - Health - cyclotrons for the production of medical isotopes [3] and for radiotherapy
  - Industrial applications - tandems for materials characterization [4]
- Potential applications and market (validated by literature research):
  - Health – specific market
    - production of radiofarmaceuticals: stripping and production targets with innovative graphene nanoparticles integration route [5]
    - Radiotherapy: stripping and beam windows
  - Industry: graphenic membranes for harsh environments such as batteries and desalination (very large market)
- A more extended analysis of the market size and growth will be performed within this project

References:

1. W. Barth et al., “Carbon stripper foils for high current heavy ion operation”, INTDS 2012.
2. F. Marti, Heavy ion strippers, LINAC 2012, Tel-Aviv, Israel.
3. Siemens,http://www.siemens.com/mi
4. Doyle, Barney L., McDaniel, F. D., and Hamm, R. W.. *The Future of Industrial Accelerators and Applications.*. US, 2018. Web.
5. John P. Greene et al., Rhenium and iridium targets prepared using a novel graphene loading technique, EPJ Web Conf., 229 (2020) 06001

Business Plan

- *What makes your innovation attractive to accelerators scientists?*
  - Increased charge state and lifetime of stripper foils leading to better energy efficiency and less maintenance time
- *What is the intellectual property status?*
  - The fabrication of supported graphenic membrane windows for radiation detector is patented and used by KETEK
- Future application for German BMBF agency intended
- *If applicable, who are your current clients, buyers and/or revenue sources?*
  - The current clients are buyers of integrated detector systems from KETEK
  - For the stripper foil market, potential clients are accelerator laboratories and medical and industrial accelerators- interest shown within previous studies
- *Discuss commercialization, scalability, industrialization and manufacturability, etc.*
  - Development of the supported graphenic membranes to meet different geometry and thickness requests are possible; within the time scale of the project thickness variation and moderate area increase of the supported graphenic membranes are possible
  - Larger volume scaling and industrialization are possible as shown by the production for current applications as detectors beam windows

The commercialization

- *Developmennt after IIF:*
  - Further developments to meet the individual geometry and stripper foil thickness needs for accelerator applications, as well as developments for applications related to radiotherapy and industrial accelerators are planned
  - After IIF a more extended proposal for an EU project will be prepared, that will include further prototypes
- In a future potential partnership, we will be looking to attract additional funding for further developments as well as partners and potential clients to design and develop together the prototypes to their specific needs

Resources and budget

- *Team and organizational expertise dedicated to the project*

The project leader and the teams from GSI and WWU, Münster provides unique expertise in ion-induced modifications of materials and particularly in carbon materials for application in high power accelerator, including stripper foils. This is complemented by access to unique irradiation facilities at GSI with various in-situ and on-line characterization techniques. Damage characterization is performed online and post irradiation by IR thermography, high resolution electron microscopy, Raman and IR spectroscopy and diffraction methods at GSI and WWU. The team has experience in participation and management of EU projects, being involved as beneficiaries and work-package/task co-leaders in EUCARD 1 and 2, ARIES and IFAST, FP7 and Horizon 2020 projects.

- *Industry participation and involvement*

  Our industrial participant KETEK GmbH, a world's leading manufacturer of Silicon Drift Detectors will produce the graphenic membrane for tests as stripper foils in accelerators

			GSI	WWU	KETEK	TOTALS
A	Personnel and travel costs	€	100 000	76 000	10 000	186 000
B	Material and other costs	€	20 000	14 000	20 000	54 000
C	Requested IIF contribution	€	60 000	60 000	30 000	150 000

total costs:
240 000 EUR,
requested IIF contribution:
150 000 EUR

- *Expected final result output of the project*:
  - Novel stripper foil for high intensity beams based on graphenic membranes

Thank you for your attention!

Questions?

Primary Contact

Dr. Marilena Tomut

PHONE:+49 6159 71 2919 / +49 251 83-39015

MOBILE: +49 151 75228249

E-MAIL: m.tomut@gsi.de

WEBSITE: https://www.gsi.de / https://www.uni-muenster.de/Physik.MP/Wilde/Mitarbeiter/Tomut.html