Source Materials and Methods for Gallium Ion Implantation

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OBJECTIVES

Evaluate different source materials and methods for Gallium ion implantation, including gas material, different sputtering targets and a variety of co-gases.

BACKGROUND

Gallium (Ga) has been studied as an alternative p-type dopant to Boron (B) due to its higher solid solubility in Germanium (Ge) and silicon germanium (SiGe), which are used in advanced semiconductor devices for performance improvement. Recent developments in advanced PMOS devices reported that ultra low contact resistivity could be achieved by gallium doping.

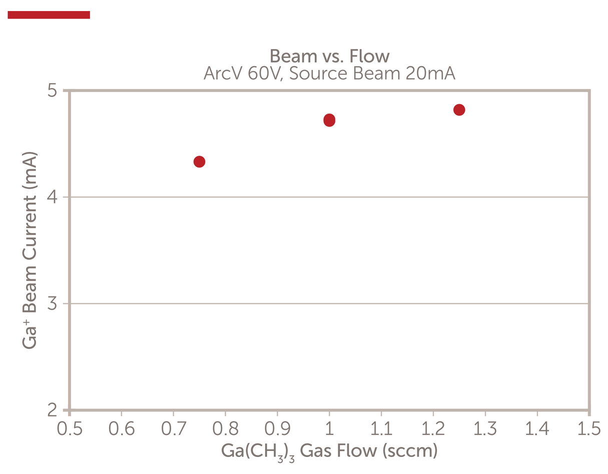
TOOL/EXPERIMENTAL SETUP

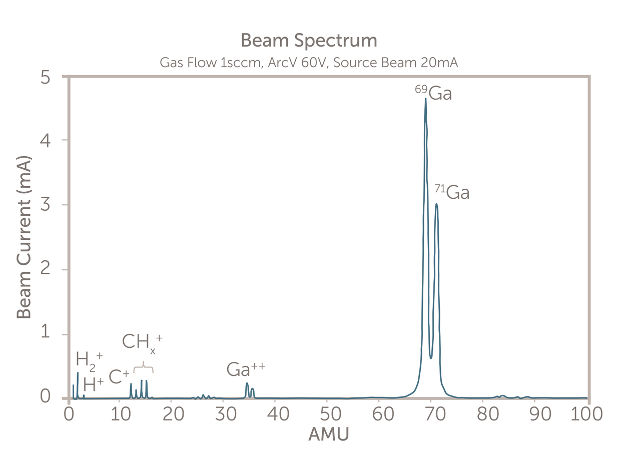
Entegris' in house implant source test stand (STS) was used for all the experiments that are presented in this poster. A typical Indirectly Heated Cathode (IHC) source with tungsten arc chamber was used. The test results presented in this paper encompass multiple individual experiments that were designed to optimize the Ga^+ beam current and source life. The first experiment conducted involved looking at Trimethylgallium (TMGa) as a dopant source for this application. The second aspect of this investigation involved determining performance of alternate dopant sources in conjunction with multiple material types and quantities of a gallium sputter target. The sputtering target configurations that were tested included:

- One piece of Gallium oxide (Ga_2O_3)
- One piece of Gallium nitride (GaN)
- One piece of Ga_2O_3 and one piece of GaN

The process gases used as a sputtering source were xenon (Xe), boron trifluoride (BF_3) and silicon tetrafluoride (SiF_4). Additionally, hydrogen (H_2) and xenon (Xe) were also used as a co-flow gas with either BF_3 or SiF_4.

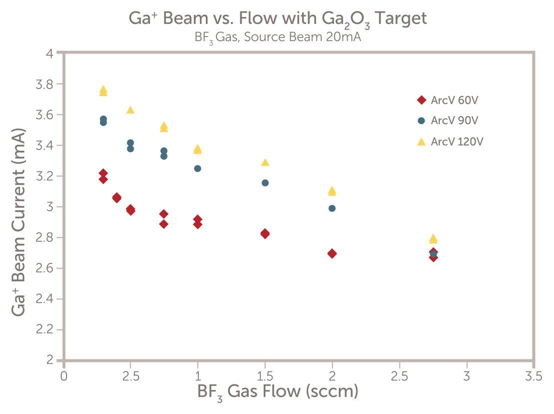
BEAM PERFORMANCE FOR TRIMETHYLGALLIUM (TMGa)

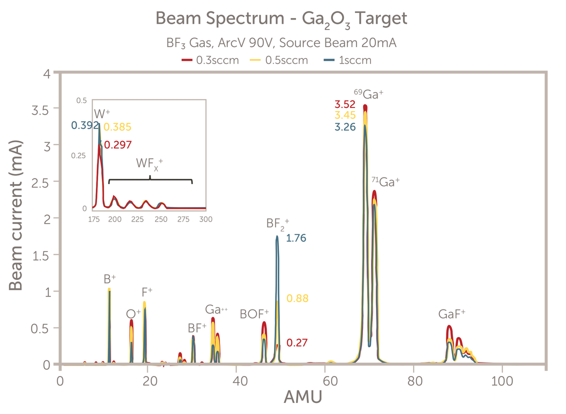




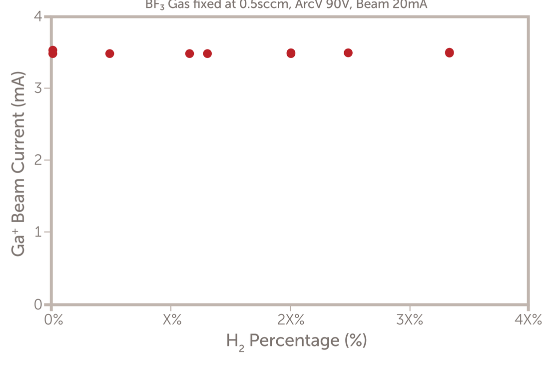
- Achieved varying Ga^+ beam currents in the range of 4 to 5 mA, depending on the TMGa flow rate as shown in the above figure.
- The beam spectrum showed high Ga^+ peaks as well as other carbon and hydrogen ions.
- While the initial Ga^+ beam current reached significant values, source life fell short of 2 hours by TMGa.

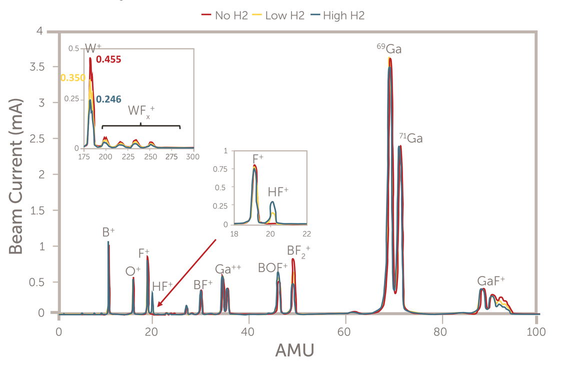
BEAM PERFORMANCE WITH SPUTTERING TARGETS – Ga_2O_3



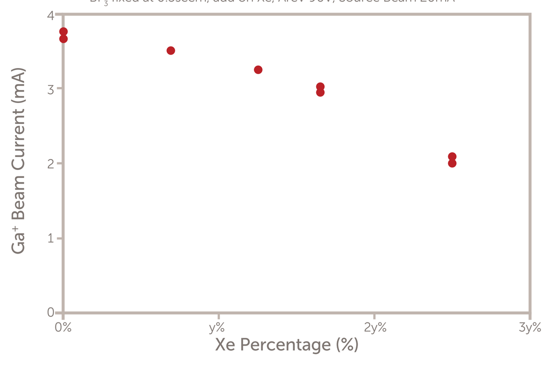


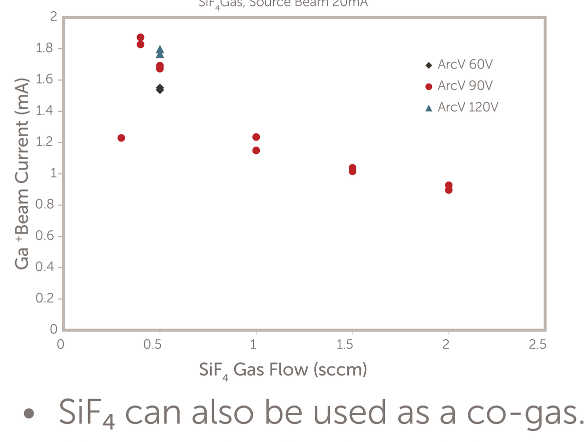
- Use of pure BF_3 allowed achievement of high Ga^+ beam current, especially at low gas flow rates and high arc voltage.





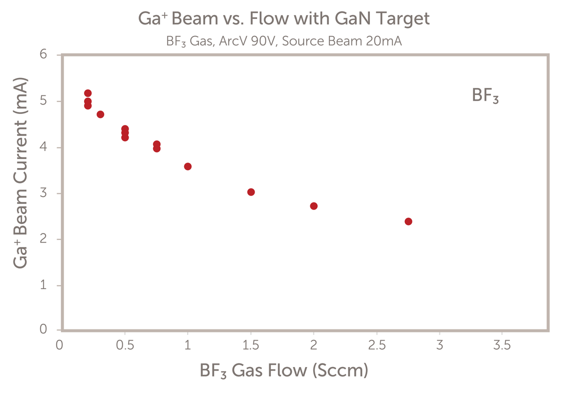
- Addition of H_2 to BF_3 reduces W^+ and WF_x^+ peaks without any significant effect on Ga^+ beam current

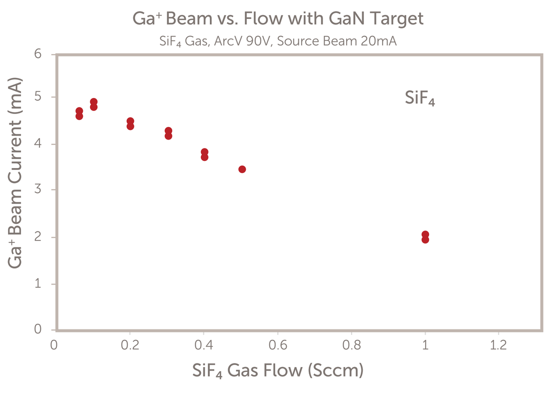


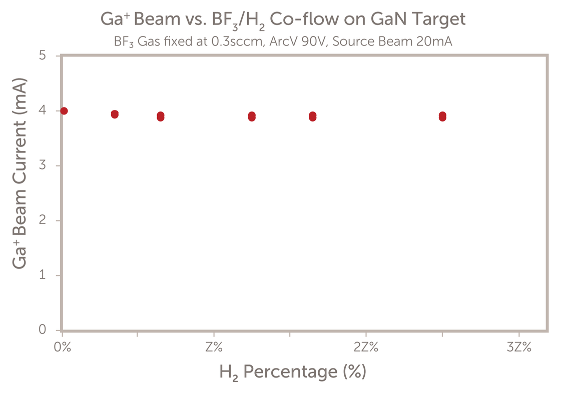


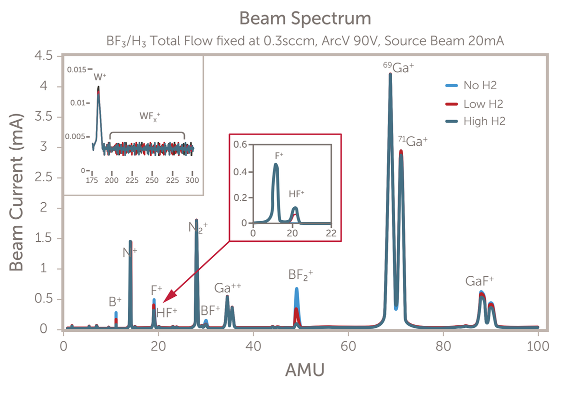
- Increase in Xe/BF_3 ratio reduced Ga^+ beam current.
- SiF_4 can also be used as a co-gas. However the Ga^+ beam is lower than BF_3.

BEAM PERFORMANCE WITH SPUTTERING TARGETS – GaN



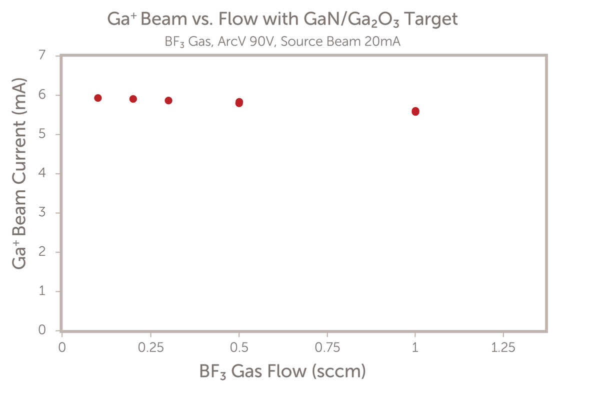




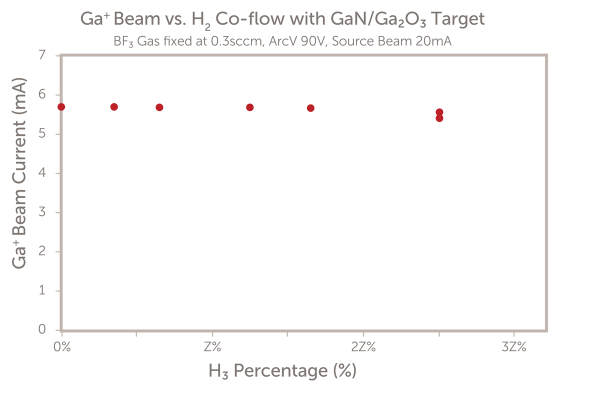


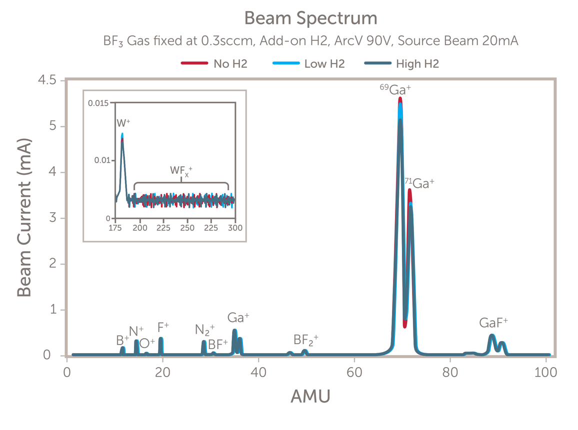
- With GaN target, both BF_3 and SiF_4 co-gases could achieve near 5 mA beam current although BF_3 is slightly better.
- Adding H_2 to BF_3 would not affect the Ga^+ beam current with GaN target.
- The W^+ peaks with GaN target are already very low and no major changes with adding H_2.

BEAM PERFORMANCE WITH SPUTTERING TARGETS – Ga_2O_3/GaN



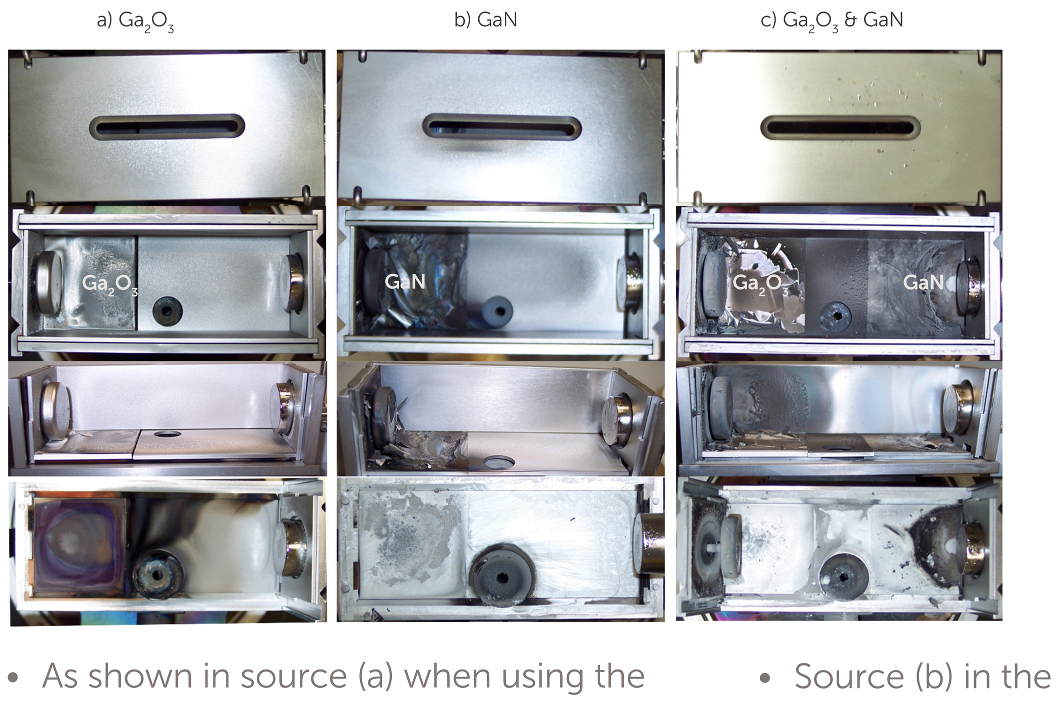
> Highest beam current at ~6mA was achieved with Ga_2O_3 and GaN target.
>
> *Note: Target surface area is doubled as compared to the Ga_2O_3 or GaN target tests previously discussed in this poster.





- Adding H_2 to BF_3 would not affect the Ga^+ beam current
- The W^+ peaks are very low and no major changes with adding H_2.

SOURCE CONDITIONS AFTER TESTING OF EACH SPUTTERING TARGET



- As shown in source (a) when using the Ga_2O_3 sputter target the source condition looked relatively clean with little visible deposits. Upon removing the Ga_2O_3 base plate, significant discoloration was noticed in this area, however there was little signs of any flakes.
- Source (b) in the picture above shows the condition when using the GaN sputter target. As can be seen there were flakes and residue present near the anti-cathode.
- Source (c) shown above included both the Ga_2O_3 and GaN liners and residue was present at both the cathode and anti-cathode sides.

*Note: The Ga_2O_3 and GaN targets in source (c) were reused from source (a) and (b).

CONCLUSIONS

- TMGa can produce a reasonable Ga^+ beam current with clean beam spectrum showing low carbon and hydrogen related peaks. However, the source life in this test was very short (<2-hours) due to the added carbon residue and makes the use of TMGa prohibitive in the application.
- Comparing Ga_2O_3 and GaN sputtering target, GaN could achieve higher beam current, however the source condition wasn't as clean as was seen with Ga_2O_3 over the course of this test. In addition, flakes were formed within the arc chamber when using the GaN target which could ultimately present a source life issue.
- When BF_3 and SiF_4 were tested with either the Ga_2O_3 or GaN sputter target, BF_3 resulted in a higher beam current than SiF_4. This was especially true when just the Ga_2O_3 sputter target was used.
- Utilizing a mixture of BF_3 and H_2 significantly reduced the formation of W^+ peaks in the beam spectrum, especially with the Ga_2O_3 target. The reduction of tungsten indicates that the addition of hydrogen is an effective disrupter of the halogen cycle and will result in a longer source life. In addition, hydrogen did not have any impact on the Ga^+ beam current in any of the conditions tested. The fact that the Ga^+ beam current is insensitive to H_2 concentration allows for the mixture concentration to be adjusted to enable longer source life with minimal impact to beam current.
- The addition of multiple targets (one Ga_2O_3 and one GaN) yielded higher beam current but was not directly proportional to the increase in surface area.

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