Investigation of Various GeF_4 Gas Mixtures for Improvement of Germanium Ion Implantation

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OBJECTIVE

Evaluate various GeF_4 gas mixture compositions for improving germanium ion implantation performance.

BACKGROUND

Germanium implant is commonly used in advanced semiconductor device manufacturing as one of the major material modification steps. Germanium Tetrafluoride (GeF_4) is almost exclusively used as the primary source gas and its impact on ion source performance (poor source lifetime due to fluorine-induced halogen cycle) is well known.

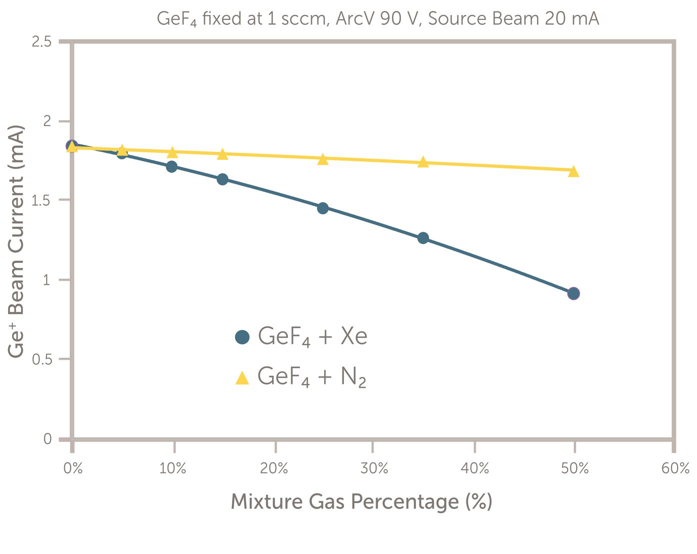
TOOL / EXPERIMENTAL SETUP

All of the experiments presented in this poster were performed on an implant source test stand (STS) which is located at Entegris. In this test, an Indirectly Heated Cathode (IHC) source with tungsten (W) arc chamber and liners were used as this represents the most typical ion source configuration used in the field. During the beam current performance test, the beam current was normally run under the fixed source beam at 20 mA. Additional tests were run for certain conditions in which the arc current was fixed at 2 A, and these results are also presented in this poster. Other major beam parameters were set up as shown below unless noted otherwise:

- Arc voltage 90 V
- Extraction voltage 20 kV
- Suppression electrode voltage 3 kV
- Source magnet and electrode positions were optimized for each beam condition

Tests were run on different dates and times. A standard Ge^+ beam using pure GeF_4 was run every day to record the tool baseline condition. Beam currents were then normalized to that condition for comparison.

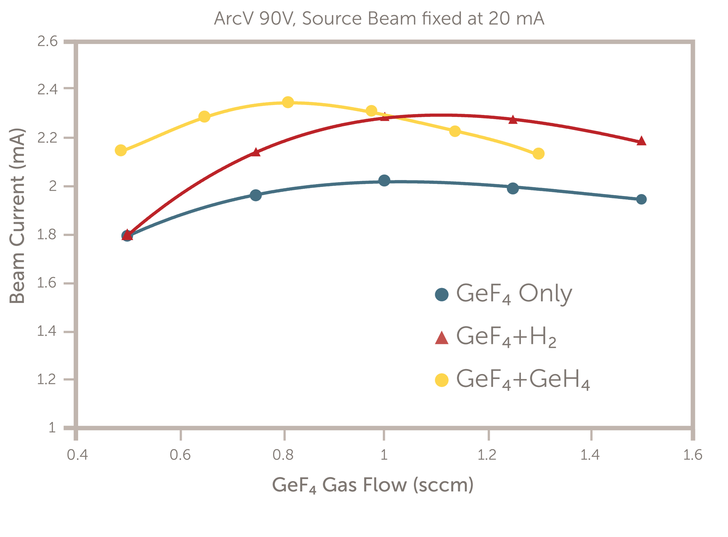
GeF_4 with Xe or N_2 co-flow



- Overall the additional N_2 or Xe caused a negative beam current impact due to the dilution of the dopant species with the co-gas.
- Xenon caused a greater drop in Ge^+ beam current when co-flown with GeF_4 relative to nitrogen.

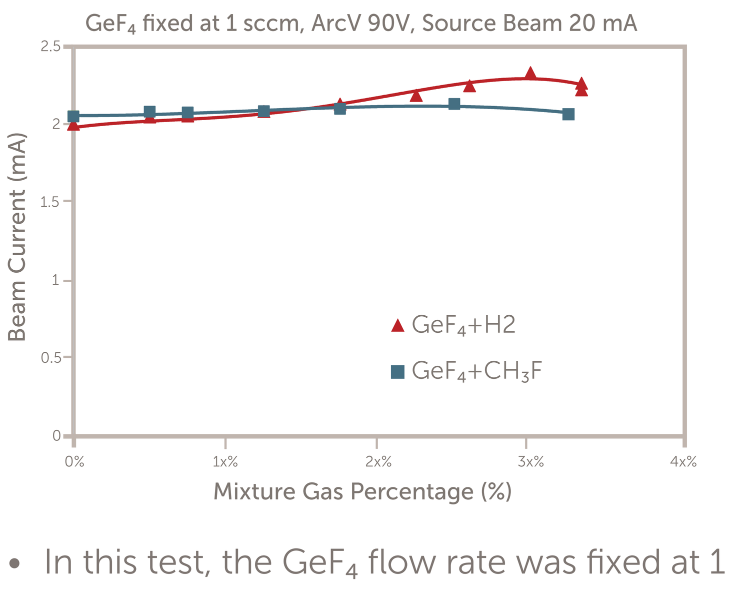
** The GeF_4/H_2 and GeF_4/GeH_4 have the equivalent amount of "H" in each mixture.*

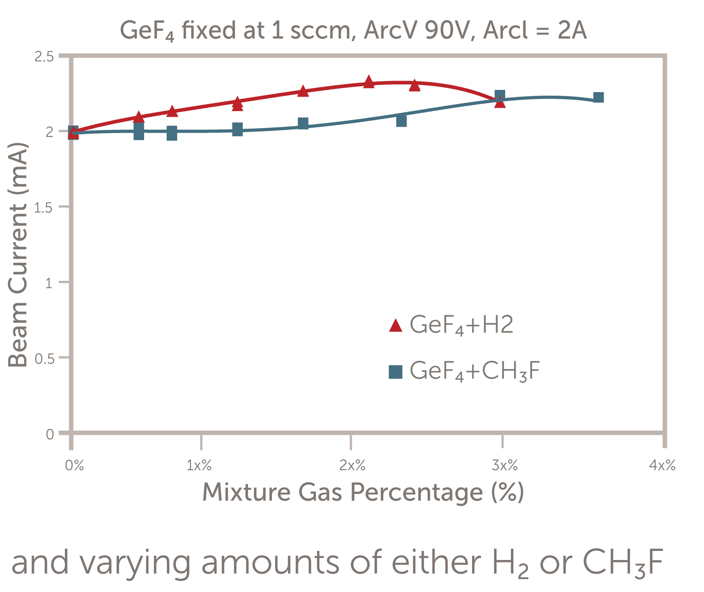
GeF_4 with GeH_4 or H_2 co-flow



- Both GeF_4/H_2 and GeF_4/GeH_4 showed ~14-15% in Ge^+ beam current over pure GeF_4.
- GeF_4/GeH_4 achieved the maximum beam current at a lower GeF_4 flow rate due to the additional Ge that is present from the inclusion of germane in the mixture.
- GeF_4/GeH_4 co-flow generated ~2% higher peak beam current relative to that of GeF_4/H_2
- After running the GeF_4+GeH_4 combination there was a significant amount of residue observed in the source area due to decomposition of the germane. In subsequent tests, which did not include Ge containing gases, the Ge^+ beam peak was observed indicating that the residue was contaminating the beam.

GeF_4 with CH_3F or H_2 co-flow

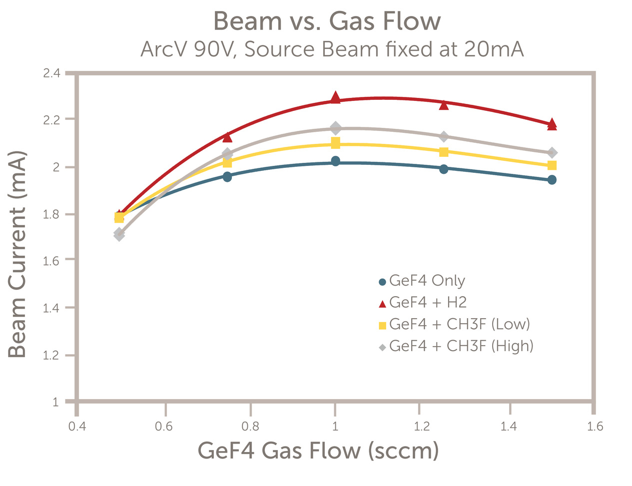


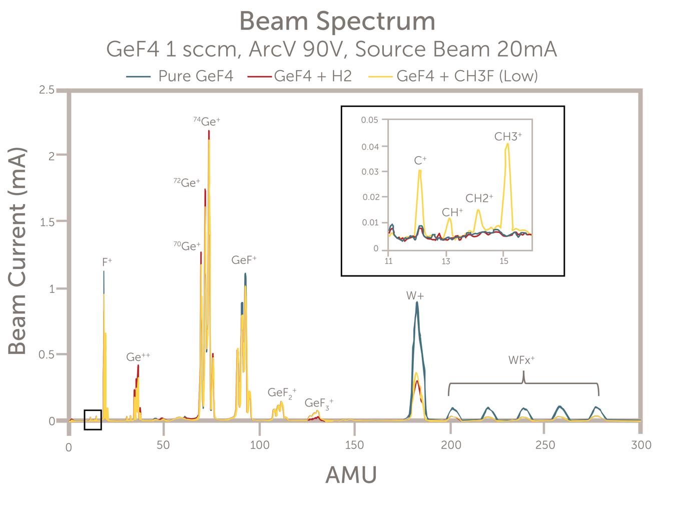


- In this test, the GeF_4 flow rate was fixed at 1 sccm and varying amounts of either H_2 or CH_3F were co-flowed in order to test the impact on the beam current. Two beam control modes were tested - source beam at 20 mA or arc current at 2 A.
- In fixed source beam mode, Ge^+ beam was improved by ~17% by GeF_4/H_2 and less than 5% by GeF_4/CH_3F.
- Under fixed arc current mode, Ge^+ beam was increased by ~17% by GeF_4/H_2 and ~12% by GeF_4/CH_3F.

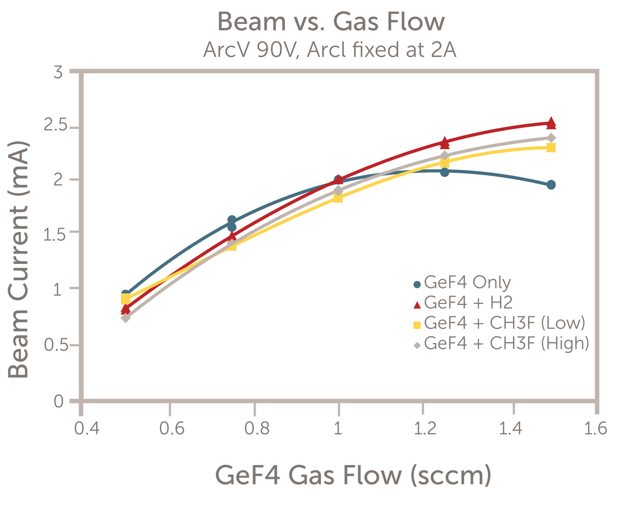
GeF_4/H_2 and GeF_4/CH_3F Co-flow (fixed ratios)

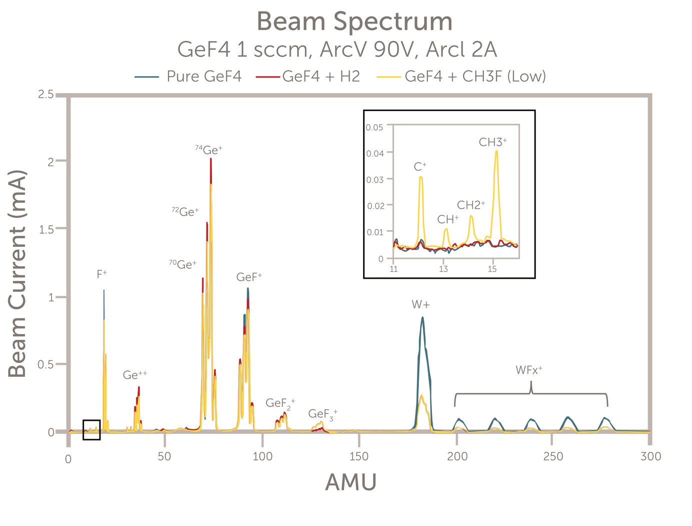
Fixed Source Beam at 20 mA





Fixed Arc Current at 2 A

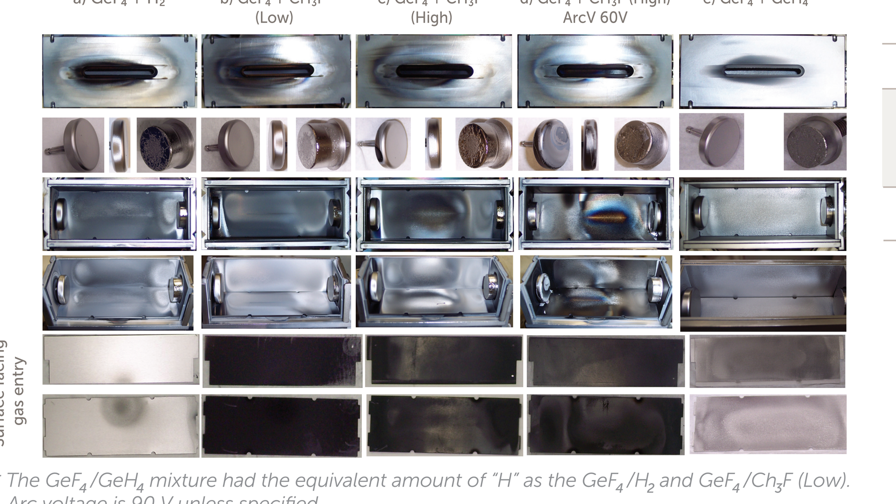




** GeF_4/H_2 mixture had the same mixture percentage as the $GeF_4 + CH_3F$ (High) condition and the equivalent amount of "H" as the $GeF_4 + CH_3/F$ (Low) due to 2 "H" in H_2 and 3 "H" in CH_3F.*

- Overall, GeF_4/H_2 mixture had the highest beam current then followed by $GeF_4 + CH_3F$ (High) and $GeF_4 + CH_3F$ (Low) conditions.
- Both H_2 and CH_3F could reduce the W^+ and WF_x^+ beams due to the added hydrogen.
- The by-product of CH_3F, such as C^+ and CH_x^+, could be observed in the small insert chart.

SOURCE CONDITIONS – 11 HOURS SHORT SOURCE LIFE TEST



** The GeF_4/GeH_4 mixture had the equivalent amount of "H" as the GeF_4/H_2 and GeF_4/CH_3F (Low). Arc voltage is 90 V unless specified.*

EDS Analysis on Flakes and Residues from Source (d) $GeF_4 + CH_3F$

Location	C (at.%)	W (at.%)	F (at.%)	Ge(at.%)	O(at.%)
Residue/coating Underneath base liner	71.86	23.76	0.26	0.06	4.06
	73.22	21.23	0.22	0.00	5.33
Flake from anti-cathode	72.97	21.64	0.15	0.10	5.14

Test Condition	Cathode Weight Change (g/Hour)
Pure GeF_4	0.415
GeF_4/H_2	-0.036
GeF_4/CH_3F (Low)	0.076
GeF_4/CH_3F (High)	-0.044
GeF_4/CH_3F (High) ArcV 60V	0.043
GeF_4/GeH_4	-0.133

- Source (a) with H_2 co-flow looked relatively clean.
- Due to the carbon content of the CH_3F, significant black carbon residue was observed in source (b), (c) and (d) especially on the liners facing the gas entry.
- Flakes and residues were observed in sources with CH_3F and also highlighted in source (d). EDS analysis of the flakes and residue show a high carbon concentration which confirms the visual observations seen when running a co-flow of CH_3F

  *Note: Oxygen in EDS is commonly seen once the once the parts have been exposed to air.
- Co-flowing with hydrogen, GeH_4 or CH_3F shift the cathode weight change to be negative; however GeF_4/H_2 is the most neutral, which is optimal, without any of the negative source life impact of using GeH_4 or CH_3F.

CONCLUSIONS

- The test results presented in this poster comparing various GeF_4 gas mixtures with a pure GeF_4 base-line show the following:
  - Co-flow with inert gases, such as N_2 or Xe, generally reduces Ge^+ beam current.
  - GeH4 co-flow enables improvement in beam current, as does co-flow with hydrogen. However, during our test, significant Ge residue inside the source area was observed after running GeH_4 co-flow.
  - Co-flow CH_3F results in higher Ge^+ beam current than pure GeF_4. But the gain is less than GeF_4/H_2 mixture.
  - Beam spectra show that CH_3F can also reduce the W^+ beam similar to co-flowing with Hydrogen. However, the addition of CH_3F results in C^+ and CH_x^+ beam peaks being observed.
  - Due to the carbon content in CH_3F, significant carbon residues are observed. Flakes or residues can be formed and accumulate in the arc chamber which can impact performance and/or source life. EDS confirmed those flakes/residues are mainly carbon.
- After testing the different co-gases of N_2, Xe, GeH_4, CH_3F and comparing to the baseline of GeF_4, it still clearly shows that the GeF_4/H_2 mixture provides the highest beam current and longest source life performance.

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