# Fluorine Beam Performance of Fluoride Dopant Gases and their Gas Mixtures

*Sharad Yedave*, Ying Tang, Joseph Sweeney, and Joseph Despres — Entegris, Inc.*

## SUMMARY

Process efficiency is crucial and continues to challenge the implant community. Entegris presents initial results of Fluorine (F) beam evaluation of BF3, SiF4 and GeF4 dopants along with their hydrogen mixtures for process improvement and tool productivity. Beam evaluations were conducted on Entegris' Implant Source Test Stand (STS) to characterize the impact of source process conditions including dopant flow, arc power, ion source magnetic field, and hydrogen co-flow rate. Test data indicates improved fluorine performance with the following: (a) BF3 followed by SiF4 and GeF4, (b) Lower dopant gas flow, and (c) Higher arc power. Further, optimized hydrogen co-mixtures of BF3, SiF4 and GeF4 along with optimal mixture flow can significantly reduce predominance of halogen cycle and can offer solutions for source life and beam current improvements.

### Background

Fluorine co-implantation is one of the key processes in semiconductor manufacturing used in defect engineering, shallow junction formation, and material modifications. Thus, there is significant and growing interest in improving fluorine ion beam performance.

Interaction of fluorine with tungsten or molybdenum walls of ion source causes halogen cycle that severely impacts beam performance and ion source life. Entegris has been evaluating ways to improve fluorine beam performance and overcome the challenges posed by fluoride dopants by developing new solutions to improve process efficiency.

### Implant Source Test Stand (STS)

Entegris' in-house Test Stand was used for the evaluations discussed. STS is a fully functional ion implanter without a wafer handler. Tests were conducted using a tungsten arc chamber. Gas mixtures were characterized by co-flowing fluoride dopants and $H_2$ from separate gas cards.

| | |
|---|---|
| Ion source | IHC Source |
| Gas box capacity | 5 (max.) |
| Extraction voltage | 5 - 60 kV |
| Mass analyzer magnet | 1 T (max.), 80° sector |
| Mass resolution | M/Dm ~ 50 |
| Beam current (mA @ 40 kV) | 7 ($B^+$), 6 ($P^+$), 8 ($As^+$) |

## FLUORIDE DOPANT MASS SPECTRA: EFFECT OF PROCESS CONDITIONS

Electron impact ionization of dopant fluoride molecule ($AF_x$) results in dissociation ($A^+$, $F^+$ & $AF_{x-n}{}^+$, n=1-x) fragments appearing in mass spectra. For example, $BF_3$ molecule will dissociate in its fragments - $B^+$, $F^+$, $BF^+$, and $BF_2{}^+$. Typical dopant ion fragments/mass spectra, when tuned for dopant $A^+$ (= $B^+$, $Si^+$, $Ge^+$) & $F^+$ beams, under different conditions are presented for comparison.

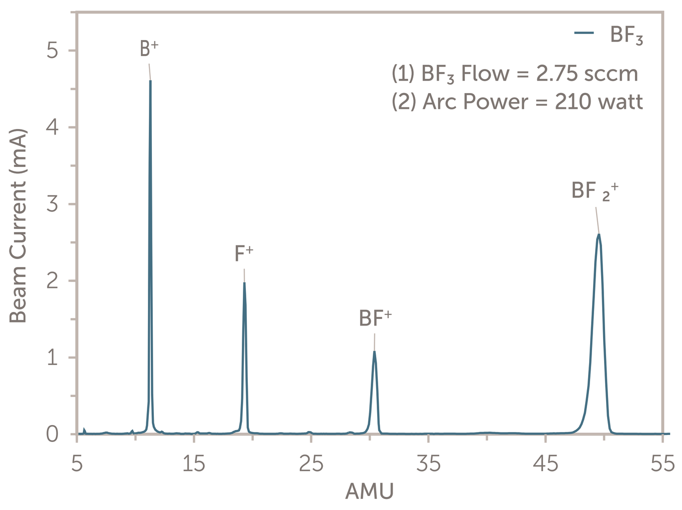
### $A^+$ (= B, Si, Ge) Dopant Beam Tuning

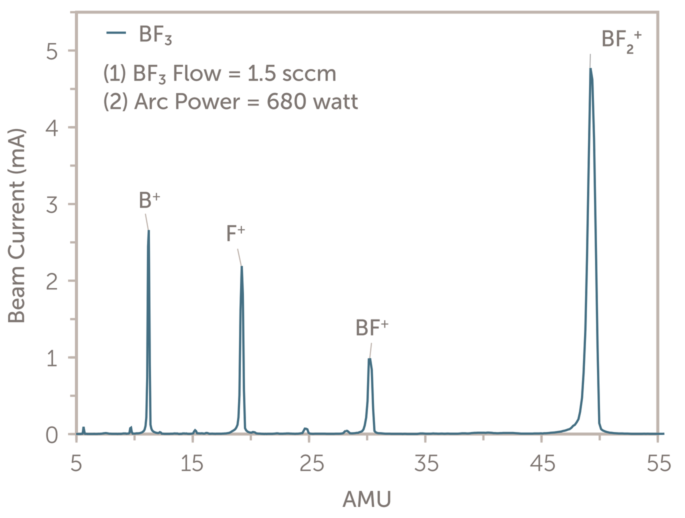
Maximizing $A^+$ with higher gas flow & source magnetic field, and lower arc power

### $F^+$ Beam Tuning

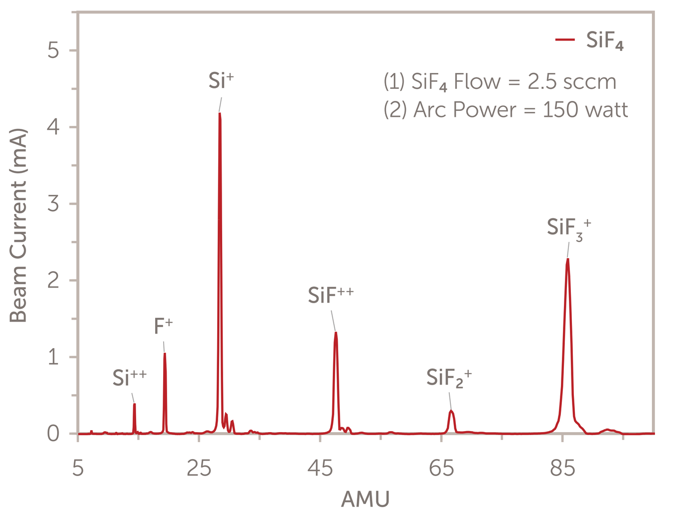
Maximizing $F^+$ with lean gas flow, lower source magnetic field, and higher arc power

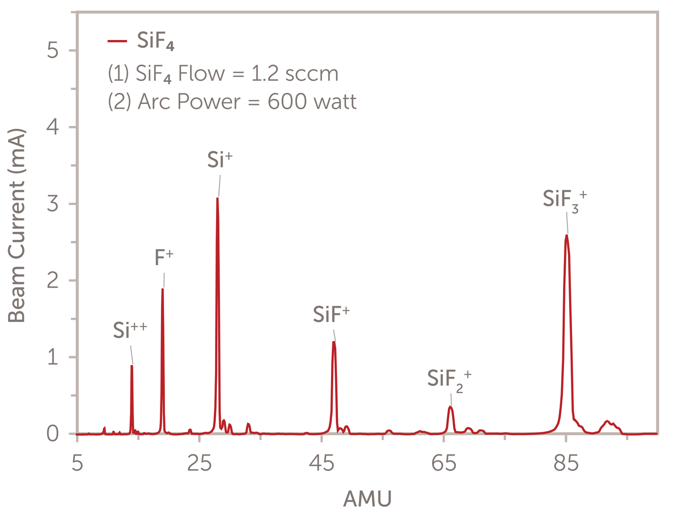
### $BF_3$ mass spectrum tuned/optimized for $B^+$ (left) and for $F^+$ (right)



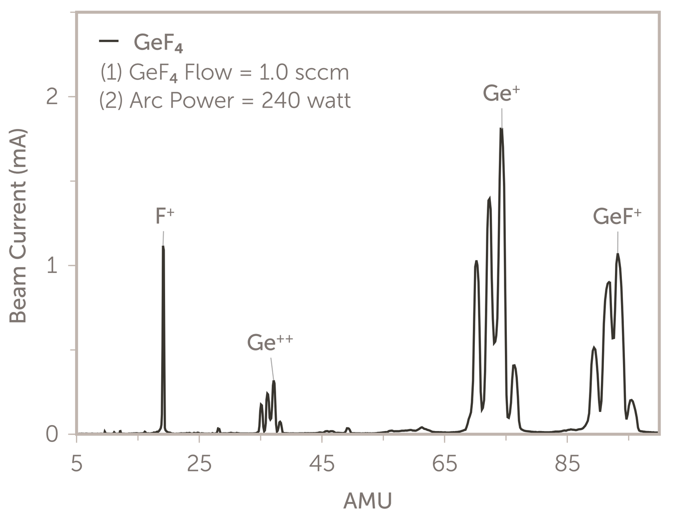



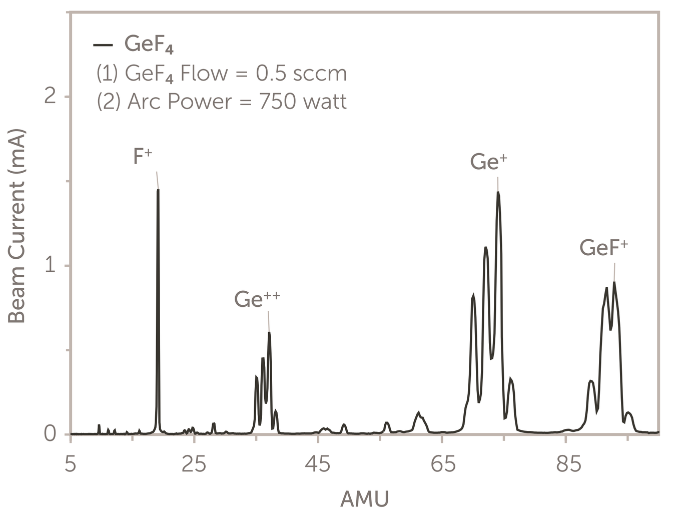

### $SiF_4$ mass spectrum tuned/optimized for $Si^+$ (left) and for $F^+$ (right)



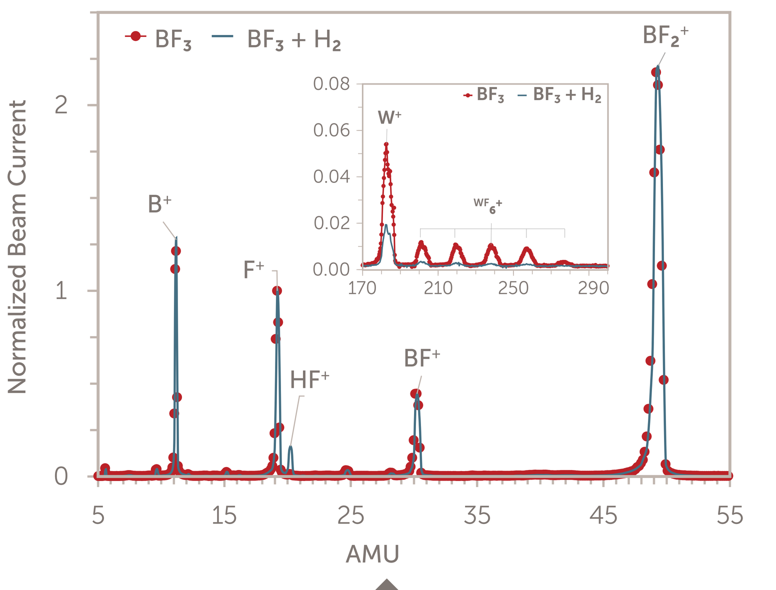

### $GeF_4$ mass spectrum tuned/optimized for $Ge^+$ (left) and for $F^+$ (right)

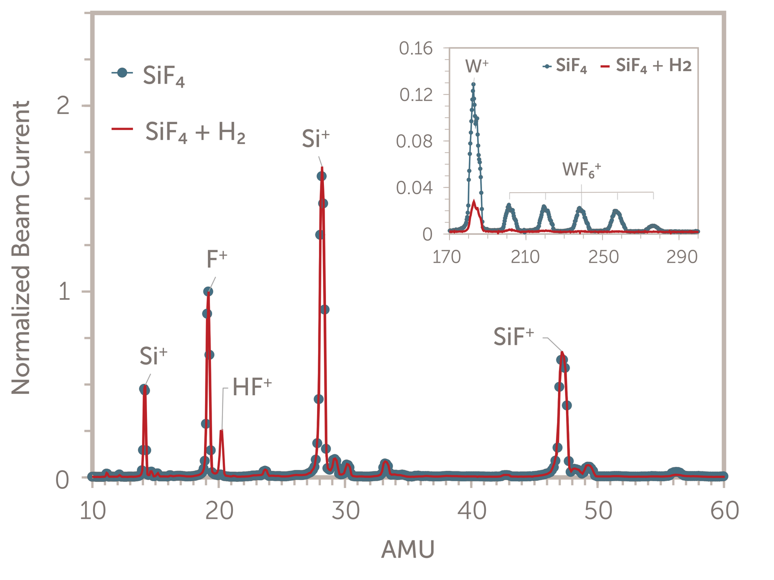


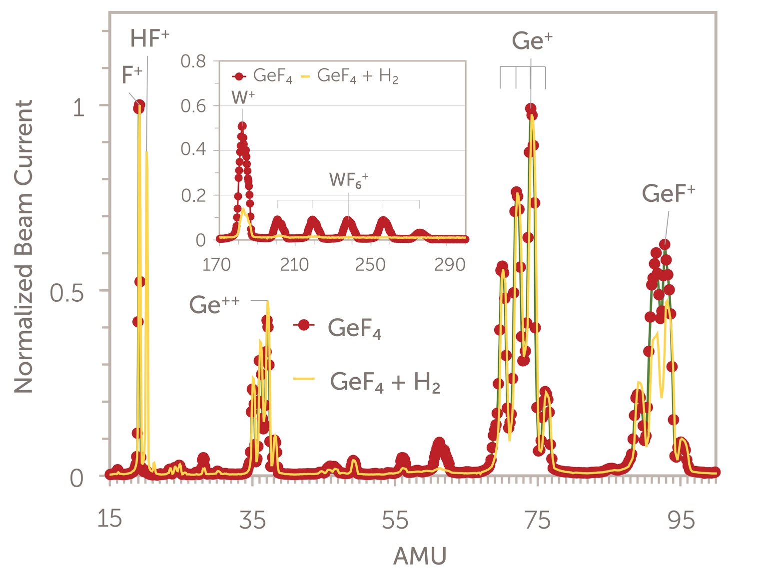

## FLUORIDE DOPANT MASS SPECTRA: IMPACT OF $H_2$ CO-FLOW

The following charts show the impact of adding $H_2$ on ion beam performance and mass spectra for each of the test dopants ( $BF_3$, $SiF_4$ and $GeF_4$). Also included for each test dopant is an inset chart which focuses on the AMU region for $W^+$ and $WF_x{}^+$ in order to show the impact of the hydrogen addition on reducing tungsten transport.




Normalized mass spectra of $BF_3$, $SiF_4$, & $GeF_4$ shows typical dopant fragments both for without and with $H_2$ case, except for a major difference – spectra with $H_2$ showing significantly lower $W^+$ (tungsten) & insignificant $WF_x{}^+$ (tungsten fluoride, x=0-5) byproducts. Note the increasing order of vertical scales in inset charts for respective fluorides - $BF_3$ < $SiF_4$ < $GeF_4$.

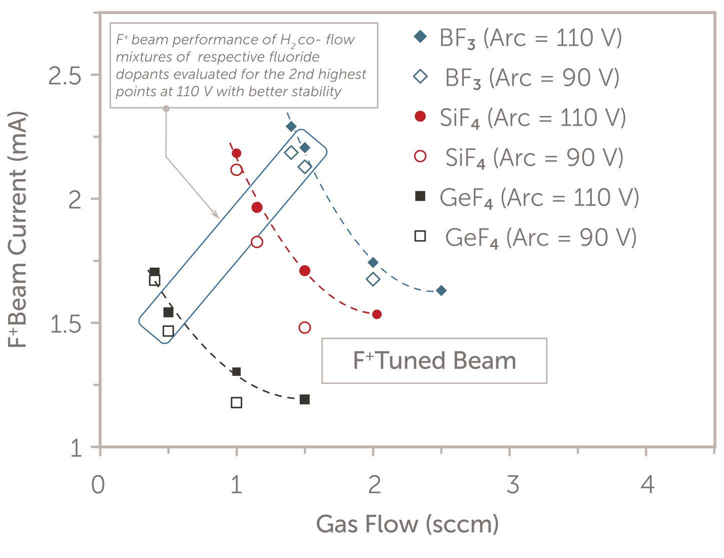



## $F^+$ BEAM PERFORMANCE: IMPACT OF DOPANT AND $H_2$ CO-FLOW

Effect of fluoride dopant flow with varying levels of hydrogen co-flow was characterized by evaluating the $F^+$ ion beam performance as well as the impact on the W byproduct amount and can be seen in the following charts.

Baseline $F^+$ beam performance of fluoride dopants as a function of gas flow rate with highest noted $F^+$ beam current of over 2 mA @ 1.5 sccm and 110 V of arc for $BF_3$, followed by $SiF_4$ and $GeF_4$

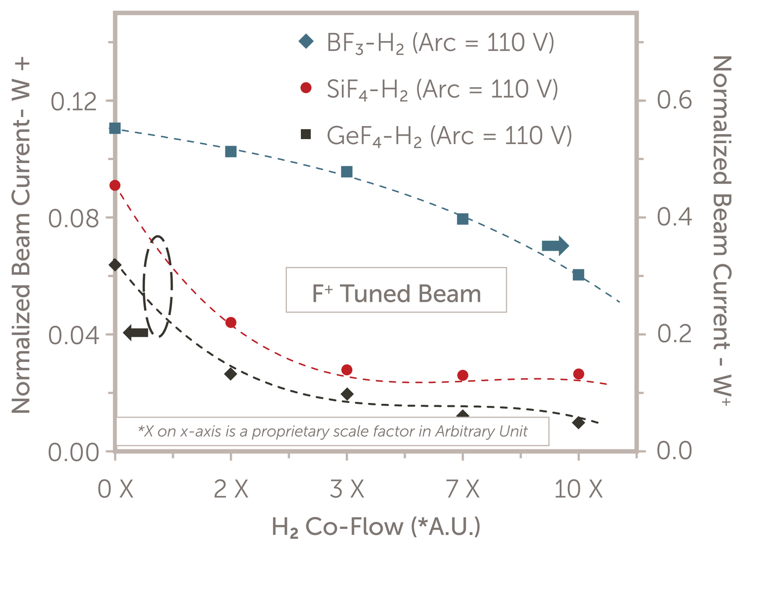
### Effect of fluoride dopants flow on $F^+$ beam performance



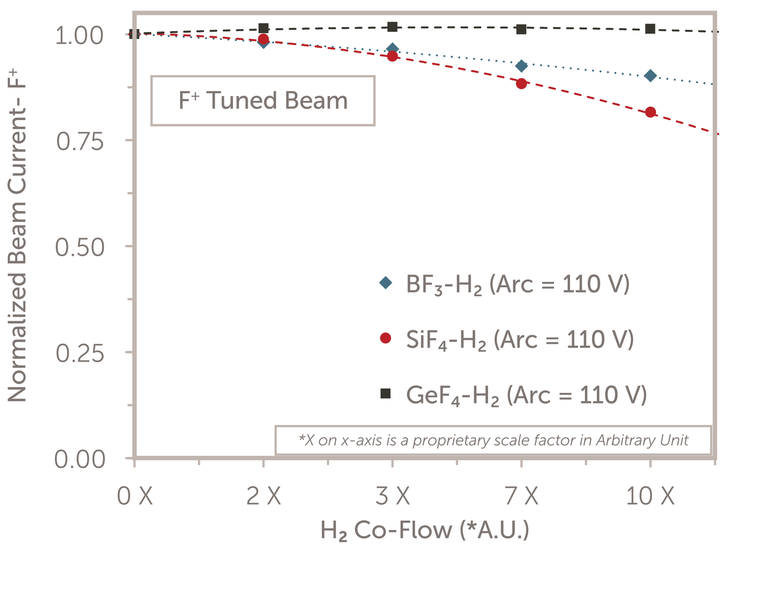

Reducing tungsten byproducts with increasing $H_2$ co-flow; $W^+$ drops continuously for $GeF_4$, whereas, it eventually stabilizes for $BF_3$ and $SiF_4$

Insignificant impact over wide $H_2$ co-flow range for $GeF_4$, whereas, slow reducing $F^+$ beam trend for $BF_3$ and $SiF_4$

### Effect of $H_2$ co-flow on W-Tungsten byproduct when using fluoride dopants




### Effect of $H_2$ co-flow on $F^+$ beam performance of fluoride dopants




## CONCLUSIONS

- Highest $F^+$ beam with $BF_3$ followed by $SiF_4$ than $GeF_4$
- Higher $F^+$ beam at ~ 50% lower fluoride dopant flow with lower source magnetic field at the expense of over ~ 200% higher arc power than the typical dopant tuning conditions
- Optimized $H_2$ co-mixture of fluoride dopants offer better solution with longer source life and beam current.