Title
CRADA Final Report: Development of Negative Heavy Ions for Ion Implantation

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CRADA Final Report
CRADA No. 02-353

1. Parties: (Identify Parties to the CRADA)

The Regents of the University of California/Lawrence Berkeley National Laboratory
AXCELIS TECHNOLOGIES, INC.

2. Title of the Project: Development of Negative Heavy Ions for Ion Implantation

3. Summary of the specific research and project accomplishments:

The goal of the research project was the development of a sputtering type surface ionization source to produce negative boron ions for semiconductor industry applications. Some existing sources of this type are relying on heavy cesiation of a lanthanum hexaboride (LaB_6) sputtering target to increase the negative boron yield to about 1 - 2 mA/cm^2. In commercial ion doping machines the cesium is an unwanted impurity, as it gradually coats the insulator surfaces of the acceleration column and causes voltage break downs. The goal of the research was to build an ion source capable of producing commercially attractive currents of negative boron without using cesium.

In the initial phase of the experiment, a large multicusp- type, RF driven ion source with a 20 mm diameter LaB_6 sputtering target/converter was set up for testing. Argon and xenon gases were used to create the background plasma. No negative boron atoms were observed in the measurements within the accuracy of the mass spectrometer, but large peaks corresponding to B_2^- and B_3^- clusters were seen. A very minor B_4^- cluster was also observed in some measurements. The appearance of boron clusters suggests that the structure of the LaB_6 lattice, which is an octahedron with a boron atom in each corner and a lanthanum atom in the middle, is favorable for cluster emission when bombarded by 1 keV argon ions. In the case of argon plasma, a current density of 0.14 mA/cm^2 of B_2^- and 0.09 mA/cm^2 of B_3^- was achieved. For xenon plasma, the current densities of B_2^- and B_3^- were 0.06 mA/cm^2 and 0.08 mA/cm^2, respectively.

These currents were too low to be commercially applicable. However, by building a smaller non-cesiated ion source with higher power density, with optimized source design and a larger converter, it was possible to increase the negative boron currents further. To achieve this, a compact ion source with an external RF antenna and 50 mm diameter LaB_6 converter was constructed. The source was designed to optimize the B_2^- current by using argon plasma. 1 mA/cm^2 of B_2^- and 0.44 mA/cm^2 of B_3^- was extracted from the external antenna source at 800 W RF power. The total extractable B_2^- ion current was determined to be 1.8 mA. These values are comparable to values reported by other research groups employing cesiated, internal antenna ion sources. The non-cesiated, external antenna ion source would offer a reliable, clean way of producing negative boron ions for ion implantation applications.

4. Deliverables:

Deliverable Achieved	Party (LBNL, Participant, Both)	Delivered to Other Party?
Research data	LBNL	Axcelis
No hardware deliverables		

5. Identify publications or presentations at conferences directly related to the CRADA?

S. K. Hahto, *Development of negative ion sources for accelerator, fusion and semiconductor manufacturing applications,* PhD dissertation, University of Jyväskylä, Department of Physics research report No. 4/2003,ISBN951-39-1574-3, ISSN 0075-465X

S. K. Hahto, S. T. Hahto, J. Kwan, K. N. Leung, L. R. Grisham and K. Saadatmand, *Negative ions for heavy ion fusion and semiconductor manufacturing applications,* submitted to Rev. Sci. Instrum at ICIS 2003.

6. List of Subject Inventions and software developed under the CRADA:

Patent application: "Negative Ion Source with External RF Antenna", IB-1826A (U.S. Patent Appl. Serial number 10/656,848)

7. A final abstract suitable for public release:

In ion implantation, the charging up of the target material can be avoided by using negative ions instead of positive ones. Boron is the most commonly used dopant in manufacturing of p-type semiconductors. A sputtering type, surface production ion source capable of producing commercially applicable amounts of negative boron ions from Lanthanum Hexaboride (LaB_6) was constructed and tested. A new design using an external RF antenna and non-cesiated source operation was implemented. The ion source performance matched that of other existing sources, which are using additives like cesium. The non-cesiated operation increases the reliability and lifetime of the ion source and acceleration system, and makes the source operation easier.

8. Benefits to DOE, LBNL, Participant and/or the U.S. economy.

This study has shown the commercial viability of a new type of ion source using innovative external RF-antenna design. This type of external antenna, negative ion source can be used in various different DOE and LBNL projects, ranging from negative ion injector for large accelerator systems to sources designed for material modifications and studies. For Axcelis Technologies this study is providing a base line design for reliable and long life-time negative boron ion beam production source to use in semiconductor manufacturing.

9. Financial Contributions to the CRADA:

DOE Funding to LBNL	$ 10k
Participant Funding to LBNL	$ 36k
Participant In-Kind Contribution Value	$ 14k
Total of all Contributions	$ 60k