

## Modified vacuum vibrator ion source for phosphorous and boron ions

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MS received 5 November 1983; revised 23 April 1984

**Abstract.** A modified version of vacuum vibrator ion source is designed, fabricated and used to obtain phosphorous and boron ions. Its main features (i) controlled amplitude of vibrations at the spark position and (ii) small quantity requirements of materials. Pure powders of boron and red phosphorous were used respectively to get boron and phosphorous ions and in each case the ion current obtained was of the order of  $1 \mu\text{A}$ . The results obtained from silver electrodes are compared with those obtained from other metal electrodes. Silver is found to be a suitable electrode material for production of phosphorous and boron ions.

**Keywords.** Vacuum vibrator ion source; spark; electrode; boron; phosphorous.

**PACS No.** 07-77; 29-10

### 1. Introduction

The importance of vacuum vibrator ion source has long been realised because of its advantages over other types of ion sources. However, it has not yet made an impact in the field of ion implantation presumably because of its low ion yield. Also, to produce ions of non-conducting elements, carbon powder is usually used to form electrodes which however provides very low ion currents.

Elements from the I, II, III, V and VIth groups (Willson and Jambe 1967) are suitable as impurities for doping semiconductors, among these phosphorous and boron are commonly used. In most ion sources, phosphorous and boron ions are obtained using gaseous compounds as feed materials. However, handling of such gaseous compounds has its difficulties.

The present paper describes a technique to obtain phosphorous and boron ions from a vacuum vibrator ion source, using red phosphorous and elemental boron respectively. The recorded ion currents indicate a possibility to implant  $10^{16}$  ions/cm<sup>2</sup> of boron or phosphorous, in a given substrate, in about 1 hr.

### 2. Theory and experimental

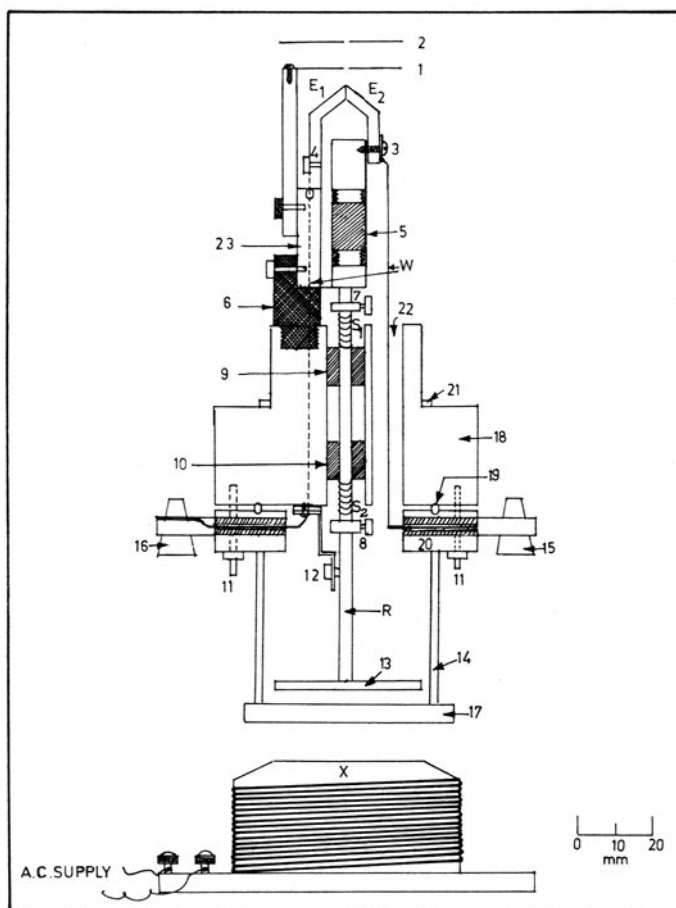
When a spark is generated between two metallic electrodes having potential difference of  $V$  volts, the maximum temperature  $\theta_m$  that can be raised at the contact point is given by (Llewellyn 1957).

$$\theta_m^2 - \theta_0^2 = V^2/4L, \quad (1)$$

where  $\theta_0$  is the room temperature and  $L$  is the Lorentz constant having a value  $2.45 \times 10^{-8}$  W ohm/deg<sup>2</sup>. This shows that even at the potential difference of 1.6 V, the

maximum temperature,  $\theta_m$  that can be reached is 5000°C. This technique is therefore suitable to produce ions of any element by properly adjusting the spark voltage and series inductance.

A vacuum vibrator ion source is modified to (i) provide more contact area at the spark position and (ii) instead of one electrode striking another (Venkatasubramanian and Duckworth 1963) the spark is generated by vibrating one electrode parallel to and in contact with a steady electrode. Both the electrodes are made of the same metal which may be aluminium, silver or stainless steel etc. Rectangular bars ( $15 \times 5 \times 4$  mm) were used for electrode formation. One end of each rod is tapered to  $45^\circ$  along the thickness and is bent to  $45^\circ$ , such that the tapered surface becomes parallel to the length of the rod. Fine holes (0.5 mm diameter), were made on the tapered surface and filled with elemental boron or red phosphorous. Identical electrodes were fitted in the ion source



**Figure 1.** Modified vacuum vibrator ion source ( $E_1$  and  $E_2$ —electrodes;  $S_1$  and  $S_2$ —springs;  $R$ —vibrating rod;  $W$ —connecting wires;  $X$ —exciter; 1—slit 1; 2—slit 2; 3 and 4—electrode filling screws; 5—teflon insulator; 6—ceramic insulator; 7 and 8—spring holders; 9 and 10—teflon bushings; 11—block fitting screws; 12—guide; 13—mild steel disc; 14—glass cylinder; 15 and 16—connectors; 17—perspex flange; 18—main block; 19—O ring; 20—brass flange; 21—O ring seat (teflon); 22—vacuum channel; 23—electrode  $E_1$  and slit 1 stand).

assembly such that the surface with holes of one electrode rub on the surface of the other electrode when longitudinal vibrations were excited in one of them.

Figure 1 shows a schematic diagram of the ion source.  $E_1$  is a steady electrode whereas the electrode  $E_2$  is fitted to the rod assembly R which can be longitudinally vibrated with the help of the exciter X. A d.c. supply (10 to 50 V) and variable inductance (100  $\mu$ H to 10 mH) are used to generate spark at the contact points of electrodes  $E_1$  and  $E_2$ . The slit-1 is fitted at 5 mm distance from the edge point of the electrode  $E_1$ . The rod R (figure 1) carrying a mild steel disc (2 mm thick and 40 mm diameter) at one end is used to vibrate the electrode  $E_2$ . When a.c. current is passed through the exciter X (electromagnet) an alternating magnetic force is exerted on the mild steel disc, which results in longitudinal vibrations of the electrode  $E_2$ , with respect to the steady electrode  $E_1$ . The amplitude of vibration can be controlled by (i) suitable adjustment of the position of the mild steel disc relative to the exciter (ii) magnitude of the current through the exciter and (iii) tensions of the springs  $S_1$  and  $S_2$ . This vibrating configuration provides powerful force on the electrode  $E_2$  for vibration and avoids welding between the two electrodes at the time of spark. The latter problem was faced by the authors while working with a system which provides transverse vibration, with feeble force on the electrode (Venkatasubramanian and Duckworth 1963). The quantity of boron or phosphorous put into the holes of the electrodes is around a few mg. In each cycle of vibration, complete flat surface area of each electrode containing boron or phosphorous is swept simultaneously by the spark and therefore the quantity of evaporated material is much more compared to the situation where one pointed electrode strikes another pointed electrode (Venkatasubramanian and Duckworth 1963).

Ions produced at the spark position are accelerated by raising both the electrodes  $E_1$ ,  $E_2$  and the slit-1 to positive potential (variable between 1 kV to 4 kV) relative to grounded slit-2. The ion source was coupled to the mass spectrometer (type 21-103C) and ion current was recorded by scanning magnetic field. Elemental boron or red phosphorous was used with silver electrodes and well-defined current peaks for boron and phosphorous ions were recorded. The analysed current under the peak area of boron or phosphorous measured using a Faraday cup assembly coupled to an electrometer amplifier, was of the order of one  $\mu$ A. Figures 2 and 3 show the currents of singly, doubly and triply charged ions of phosphorous, boron and silver at one mH series inductance and 24 V d.c. sparking voltage, measured by scanning magnetic field at an extraction voltage of 1 kV. The ion current can be further increased by proper combination of series inductance and sparking voltage (Patil *et al* 1980).

Experiments using electrodes of stainless steel, copper, aluminium, nickel and carbon were also performed and ion currents of the respective elements studied. However ions of  $\text{Cu}^{++}$  and  $\text{Ni}^{++}$  are very close to  $\text{P}^+$ . Similarly for carbon  $\text{C}^+$  is close to  $\text{P}^{++}$  and  $\text{B}^+$ . For stainless steel, in addition to the fact that  $\text{Fe}^{++}$  is close to  $\text{P}^+$ , considerable background ion currents were recorded. The electrodes of copper, nickel, carbon and stainless steel are therefore not suitable as electrode materials in this ion source. For comparison, results of phosphorous and boron ions obtained with aluminium are also shown in figures 2 and 3 along with those of silver. This shows that  $\text{P}^+$ ,  $\text{P}^{++}$  and  $\text{P}^{+++}$  are close to  $\text{Al}^+$ ,  $\text{Al}^{++}$  and  $\text{Al}^{+++}$  respectively; however boron peaks are well separated.

In silver electrode (figures 2 and 3) ion peaks for phosphorous and boron are well separated from silver peaks and also the relative magnitudes of phosphorous and boron

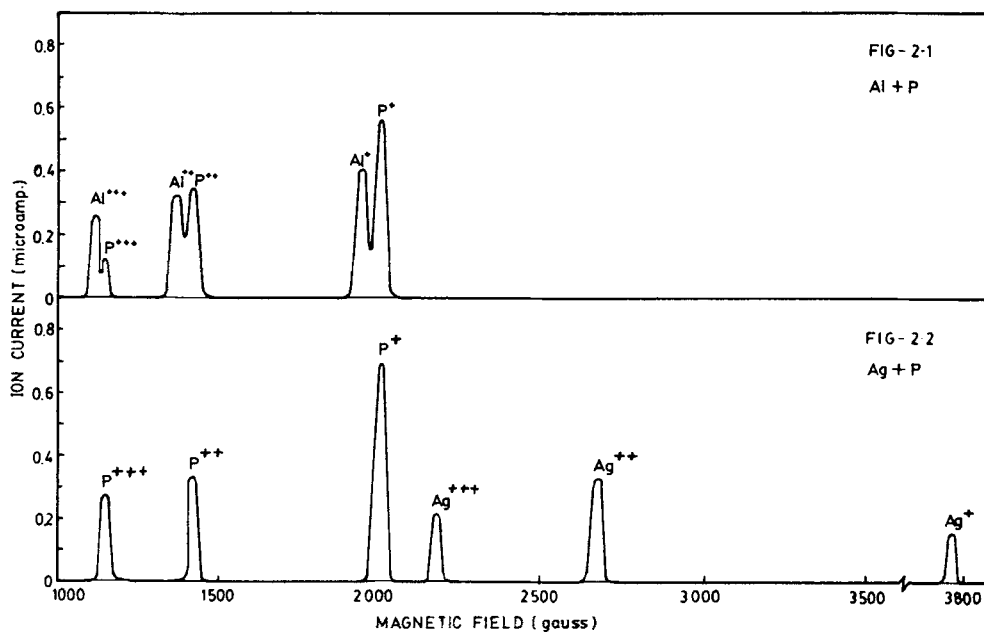


Figure 2. Ion currents of phosphorous with silver and aluminium electrode.

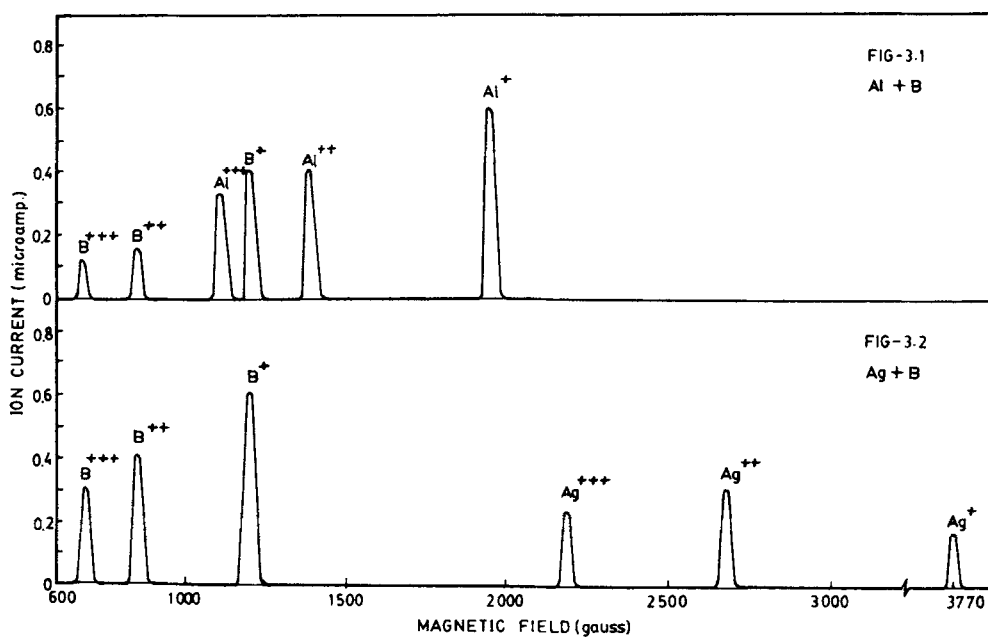


Figure 3. Ion currents of boron with silver and aluminium electrode.

currents are more compared to aluminium electrode. Figures 2 and 3 further show that abundance of ion currents depend on boiling point of the respective element.

The energy spread around 100 eV is introduced at the time of ion formation and thus depends on series inductance and sparking voltage. As reported earlier (Ramendik *et al* 1981) the mechanisms responsible for energy spread are (i) hydrodynamic acceleration and (ii) acceleration in a self-consistent electric field.

The magnitude of multiply-charged ion beam currents of this ion source is comparable with that of electron beam ion source (Clausnitzer *et al* 1975). Though the present ion source can meet the requirement of doses  $\sim 10^{16}$  ions/cm<sup>2</sup> in about 1 hr, its ion current yield is relatively low compared to PIG ion source (Baumann and Bethge 1981) where mixture of gas and metal vapour is used for ion production. However the present ion source is very easy to fabricate and does not require discharge chamber and other sophisticated mountings. Further it provides multiply-charged ion beams and as an application to ion implantation, doubly- and triply-charged ions of boron and phosphorous can be used to obtain 400 keV and 600 keV ion energies respectively by keeping the ion source at 200 kV potential.

### Acknowledgements

One of the authors (NKP) is grateful to UGC, New Delhi for providing a teacher fellowship. Thanks are also due to Prof. A S Nigavekar for encouragement.

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