DEVELOPMENT OF A POLARIZED ELECTRON SOURCE BASED ON HELIUM AFTERGLOW.

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Abstract

The Orsay polarized electron source based on the chemi-ionization reaction between aligned He 2^3S atoms and CO_2 molecules is described. The latest results obtained are presented. They reveal 82%-70% polarization for currents up to 30 μA, about 60% for 100 μA and a maximum quality factor value $IP^2 \approx 3.9\ 10^{-5}$ Amp. Further development is briefly discussed.

1. INTRODUCTION

Spin polarized electron beams are essential tools for a class of nuclear as well as atomic/molecular physics experiments. Recently, the need for highly polarized electron beams in cw accelerators has led to a considerable effort towards the development of sources combining efficiency, simplicity, and low cost. The two types of sources that look quite promising nowadays are those based on GaAs photocathodes[1] and Penning ionization reactions involving optically aligned 2^3S_1 He atoms[2,3]. The present paper is devoted to the description of the Orsay source which follows the second principle. Our aim is to demonstrate that under the light of the results presented here along with the exceptional simplicity of operation and long lifetime, this type of source fullfills in the best way the above mentioned requirements.

2. DESCRIPTION OF THE SOURCE

The Orsay polarized electron source closely follows the Rice University proposition and realisation[2]. However certain modifications permitted us to extend the current range at which an appreciable electron polarization can be obtained and to prepare it for proper installation to an accelerator environment. Its principle of operation relies on the chemi-ionization reaction between optically aligned He triplet metastables and CO_2 molecules:

$$He(2^3S_1)\uparrow\uparrow + CO_2\uparrow\downarrow \rightarrow He(1^1S_0)\uparrow\downarrow + CO_2^+\uparrow + e^-\uparrow \quad (1)$$

Reaction (1) is spin preserving and the liberated electron carries out the spin of the aligned He metastable atom. While other atomic or molecular gases can be used as targets as well, the choice of CO_2 is guided by the large chemi-ionization and electron cooling cross sections it offers. Electron cooling to thermal energies is desirable in order to avoid diffusive losses and to optimize the emittance of the electron beam formed.

A schematic presentation of the apparatus is shown in figure 1a. Purified He gas is injected in a Laval nozzle placed in a μ-wave cavity. The discharge produced excites partially He atoms to 2^3S, 2^1S metastable levels. The triplet metastable density is measured by absorption of light delivered by a single mode cw diode pump LNA laser. It is found to be 10^9 - 10^{10} cm^{-3} for the pressure range of interest which is 0.05-0.15 mbar. Absorption by singlet metastables was undetectable but the estimated $2^1S/2^3S$ population ratio is ≤0.1.

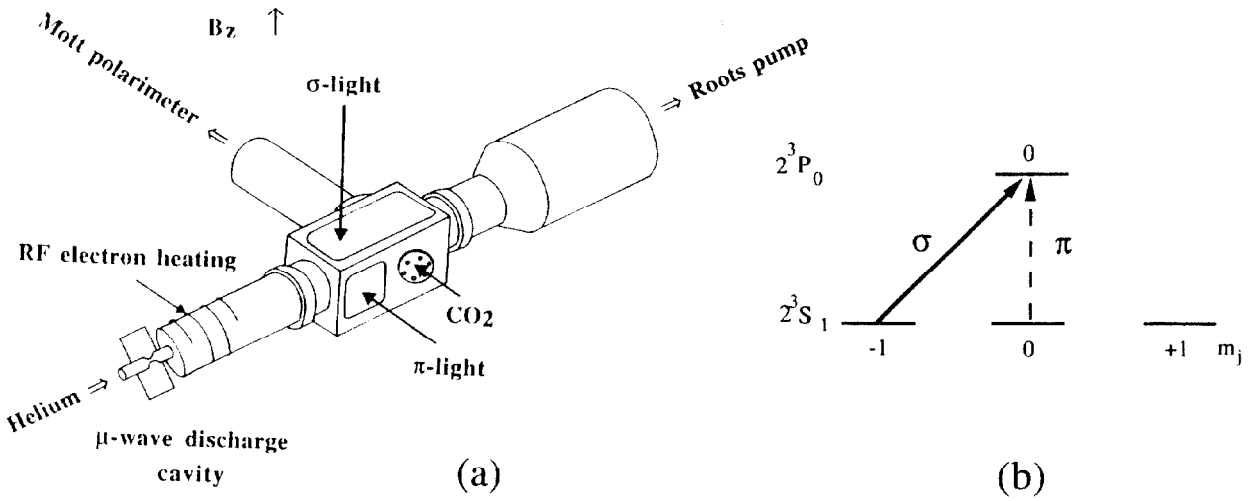

Figure 1. a) Schematic view of the source.
b) Optical pumping scheme using He $2^3S_1 \rightarrow 2^3P_0$ (D_0) transition.

The afterglow expands to a pyrex tube of length ≈30 cm. In the initial version of our source, following the design of the Rice one, an elbowed tube was used to avoid the unpolarized μ-wave discharge photons from interfering to the 2^3S_1 level alignment process. At the latest version we use a straight tube because we have not observed such an effect[6], the beam profile was found to be better and the metastable density expected to be higher. The average atomic flow velocity of ≈100 m/sec is dictated by the 1000 l/sec Roots blower evacuating the system. A 50 MHz, RF coil surrounds the tube facilitating this way the loss of parasitic electrons and ions originating from the μ-wave discharge.

Immediately after the Pyrex tube, the beam enters a metallic chamber where optical pumping and chemi-ionization reaction take place. Our optical pumping scheme involves two laser beams one circularly and one linearly polarized (see fig. 1b). They are tuned to He $2^3S_1 \rightarrow 2^3P_0$ (D_0) transition instead of the $2^3S_1 \rightarrow 2^3P_1$ (D_1) one which is more commonly used. The later transition however suffers from J-mixing between the 2^3P_1 and 2^3P_2 levels at relatively high pressures[2], resulting in a considerable depolarization or even its inversion if the pumping laser is not carefully tuned to D_1 or its linewidth is not narrow enough. On the other hand, it has been experimentally demonstrated[4] that a combination of circularly and linearly polarized light tuned to D_0 leads to almost 100% atomic polarization in a discharge cell and pressure ≈0.3 mbar. Moreover since this transition is well isolated from the $2^3S_1 \rightarrow 2^3P_{1,2}$ ones, the demand for ultranarrow laser linewidth (typically accompanied by considerable power loss) is relaxed. Our optical pumping source is a broadband (2.5 GHz FWHM), multimode, high-power (≈4 W), Kr-lamp-pumped LNA laser[5]. The experimentally measured[6] atomic polarization is found to be ≈92% for pressures up to 0.15 mbar which are enough to deliver extracted currents more than 130 μA. Helium 2^3S metastables are prepared to a selected m_j=+1 or -1 state of the 2^3S_1 level depending on the helicity of the circularly polarized beam. For efficient pumping the chamber is placed in the center of three pairs of Helmholtz coils. Their purpose is to cancel the earth's magnetic field and to provide a 2.5 Gauss highly homogeneous one ($\Delta B/B \approx 10^{-3}$), defining the quantization axis. The axis is perpendicular to the He beam as well as the electron extraction direction.

About 10 cm downstream the pumping region, CO_2 molecules are injected through a copper perforated ring and interact with the aligned atoms. CO_2 pressure is typically 0.01-0.1 times the He one. The produced electrons are extracted from the chamber through a small hole (1-2.5 mm diameter) at the center of a metallic button mounted on a plexiglass cone. Extraction is facilitated by biasing the chamber at a negative potential V_c with respect to ground ($-300 \leq V_c \leq 0$ Volts) and the button at a positive V_b with respect to the chamber ($30 \leq V_b \leq 0$ Volts). An electrostatic transport system directs the electron beam to a Mott polarimeter for the polarization measurement.

3. RESULTS AND DISCUSSION

In Figure 2 are plotted two sets of polarization (P) vs current (I) results recorded the last two years under quite different conditions. The '93 points[3], which quite nicely reproduced these obtained by the Rice University group, were typically recorded using an elbowed pyrex tube, no RF field and the chamber biased at about -300 Volts. On the other hand this year's measurements performed with a straight tube, the RF field on and the chamber grounded or biased at a lower voltage. We can observe the same high polarization for both sets at low currents and the achievement of a considerable improvement at higher ones under these latest modifications.

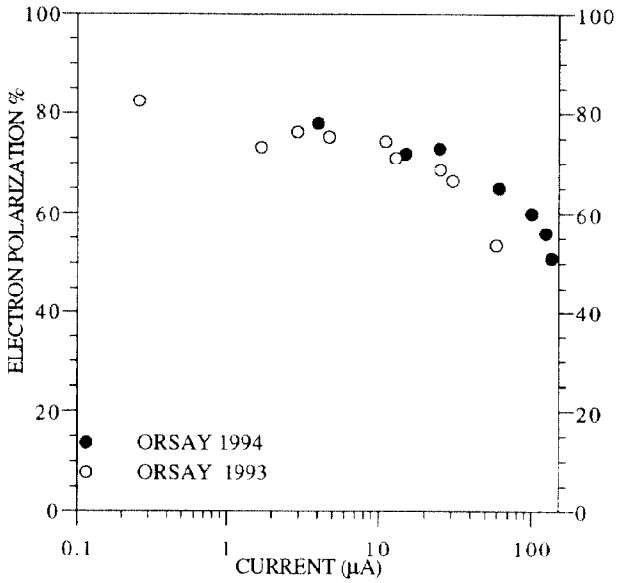

Figure 2. The Orsay polarized electron source performance for 1993 (ref. 3) and 1994. For the differences in the conditions with which these two curves were obtained see text.

Summarizing the data shown we now obtain 82%-75% polarization for 0.1-3 μA, 75%-70% for 3-30 μA, ≈65% for ≈60 μA and we reach ≈60% for ≈100 μA. In order to provide a rather unified criterion of the source's performance quality over a diversity of cw accelerator types and applications, the quality factor curve (IP^2 vs I) is shown in Figure 3. The graph reveals a maximum IP^2 value obtained of about $3.9\ 10^{-5}$ Amp.

The RF field was not used with an elbowed tube because there was no observable effect on the electron polarization. With a straight tube it was equally inefficient at low current. On the contrary its effect was dramatic for pressures ≥0.09 mbar (corresponding to currents ≥60 μA) where the polarization was almost doubled with respect to the value measured without it. However the exact mechanism responsible for this observation has not yet been understood.

Operation of the source with the chamber at ground permitted us to measure the polarization at pressures at which electrical breakdown occurs otherwise. Furthermore it is implied by safety considerations at an accelerator environment as well as for other practical purposes. For example, currently the chamber is connected to the Roots pump via an isolating

PVC tube. A grounded chamber would allow the tube's removal and the connection of the pump directly to the chamber, resulting in great space conservation and more efficient evacuation, provided a compensation of vibrations has been achieved.

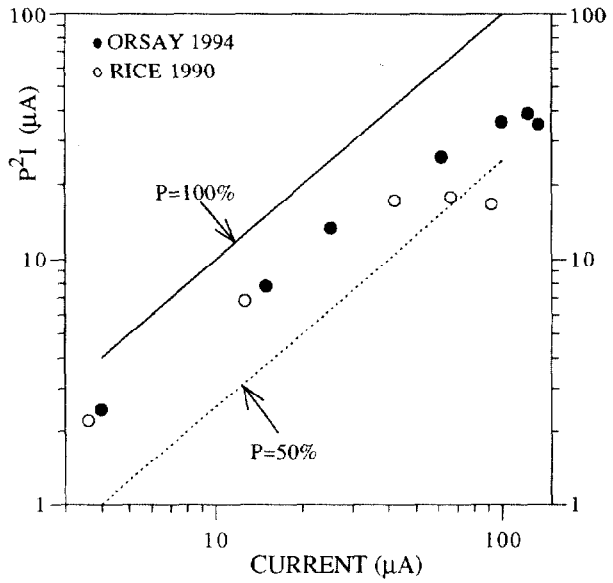

Figure 3. The Quality Factor curve of the 1994 Orsay polarized electron source performance. Together are shown the latest 1990 Rice group results (ref. 2) and the curves coresponding to 100% and 50% polarization.

We now turn to the discusion of some of the possible effects contributing to electron depolarization at high currents. First we note that for the pressure range of interest the 2^3S_1 polarization is not noticeably degraded by radiation trapping effects[6]. Various tests, such as the artificial decrease of the Roots pumping speed while keeping all the other parameters unaltered, showed that the increasing number of neutrals should also be excluded. It is then more probable that the polarization drops due to the increase of unpolarized electrons originating from the μ-wave discharge. While the use of the RF field is critical at high pressure, it is possible that it is not able to remove the totality of parasitic charges.

Further depolarization may result from spin-exchange $e+O_2^+$ or $e+O_2$ collisions. In fact equation (1) describes only one of the possible paths of the He^*+CO_2 reaction. Other products previously observed are CO, CO^+,O and O^+. Recently however, new experimental studies[7] revealed the production of O_2^+ (which may create O_2 by neutralization), scaling as the square of the CO_2 density. Considering that higher CO_2 density is necessary to produce the highest currents presented in figures 2 and 3, the existence of the above postulated mechanism seems quite probable. In addition it is further supported by preliminary experimental studies.

4. PERSPECTIVES AND FURTHER DEVELOPMENT

Our future efforts concern the full beam characterization, further increase of the polarization obtained at high currents, improvement of the source ability to be coupled to an accelerator and the more complete understanding of the physical processes taking place prior of extraction.

Experiments on the beam's energy distribution are on their way and they will be immediately followed by detailed emittance measurements. The emittance reported by the Rice group[8] (normalized $\varepsilon_n \approx 0.16\pi$ mrad mm) seems very close to that of our source as has been indicated by spot diameter measurements along the beam.

As mentioned in the introduction the operational simplicity of the source is exceptional. However in order to prove the ability of the source application to an accelerator we are still improving its routine qualities.

Understanding of the physical processes in the chemi-ionization region include several current diagnostic measurements as well as theoretical modeling. The questions to be answered concern the parameters dictating the drift of the polarized electrons and their manipulation in order to increase the efficiency of extraction while operating at moderate pressure. Additionally, extraction (and transport) of low energy electrons perpendicularly to the direction of the magnetic field seems rather inconvenient. In the near future the source will operate with the magnetic field parallel to the extraction direction. In this case the extracted electrons are longitudinally polarized. Their spin has to be rotated by an electrostatic deviator and the polarization measurement to be performed using a vertical scattering plane. For this type of measurements a new Mott polarimeter more flexible than the one which is used for the moment is under construction.

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