Progress on an optically-pumped electron spin filter

M. Pirbhai[1], E. T. Litaker[1], J. Knepper[1], N. Ryan[1], D. Tupa[2] and T. J. Gay[1]
[1]Department of Physics & Astronomy, University of Nebraska, Lincoln, NE 68588-0299
[2]Los Alamos National Laboratory, Los Alamos, NM 87545

Introduction

We are looking for more practical sources of spin-polarized electrons. Standard sources are based on negative electron affinity (NEA) strained GaAs photocathodes, which are difficult to operate. They require stringent vacuum conditions (~ 10^{-11} Torr) and lengthy, complicated activation procedures [1].

Building on previous work [2], we have devised a prototype of an optically-pumped electron spin filter. It produces polarized electrons by spin-exchange collisions with oriented rubidium (Rb) atoms:

$$e(\uparrow) + Rb(\downarrow) \rightarrow e(\downarrow) + Rb(\uparrow).$$

This device generates ~4μA of current with ~24% electron polarization (P_e), and it operates at pressures of ~10^{-3} Torr. It takes us a step closer towards the realization of a "turn-key" polarized electron source.

Setup

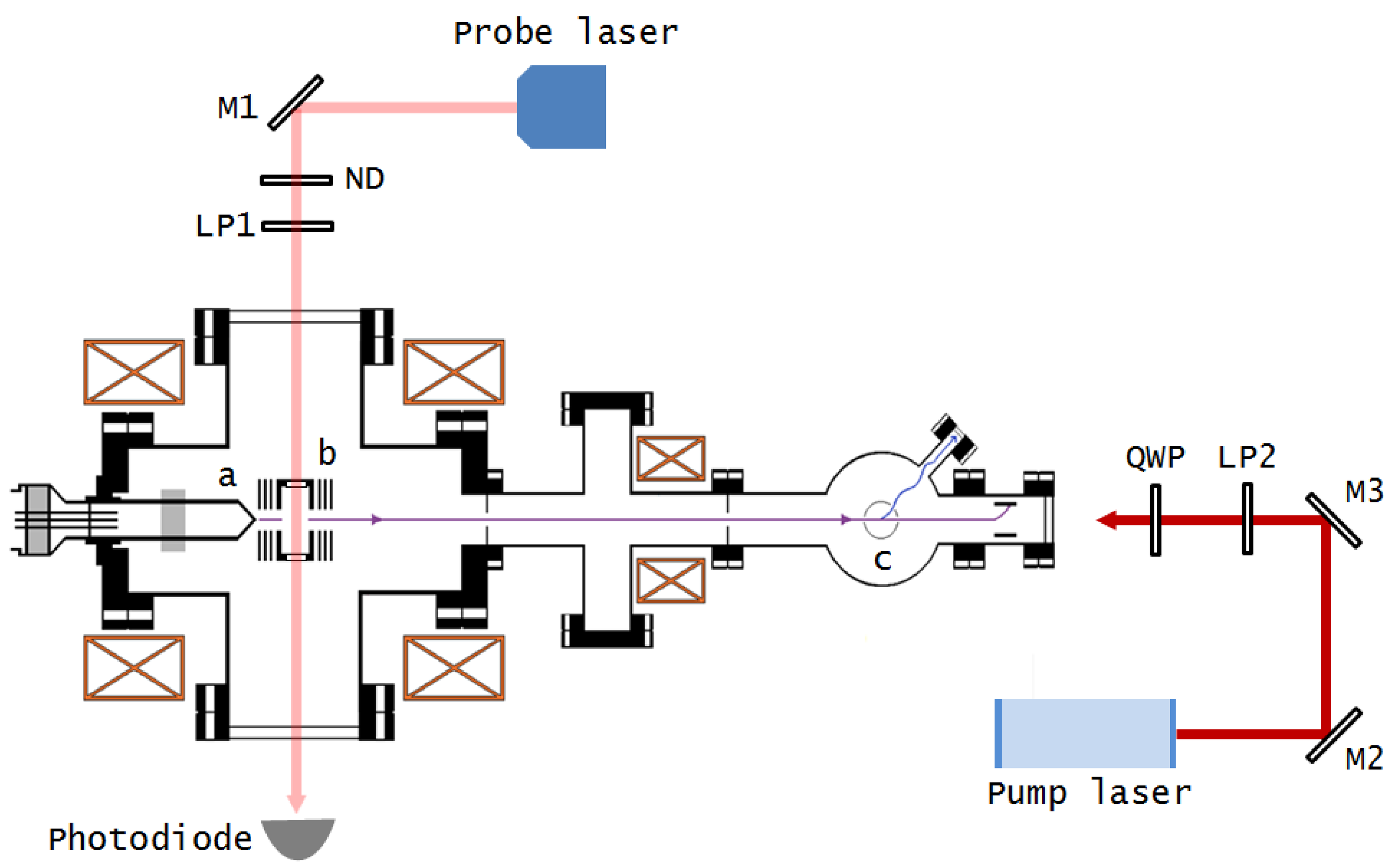

Fig. 1: Experimental layout. Here, M1-M3 denote mirrors, ND a neutral density filter, LP1-LP2 linear polarizers, and QWP a quarter-wave plate.

A tungsten filament (a) produces free, unpolarized electrons by thermionic emission (see Fig. 1). The particles are transported into the collision cell (b) where they encounter a mixture of oriented rubidium vapor and quenching gas. While drifting through the gases under the influence of an electric field, the electrons undergo spin-exchange collisions with the rubidium atoms. Once extracted from the interaction region, the electrons are accelerated into a helium electron polarimeter (c) where their polarization and current are measured.

The pump beam (~795 nm) optically pumps the rubidium atoms [3]. The probe beam monitors the thickness of the vapor by absorption spectroscopy [4].

Results

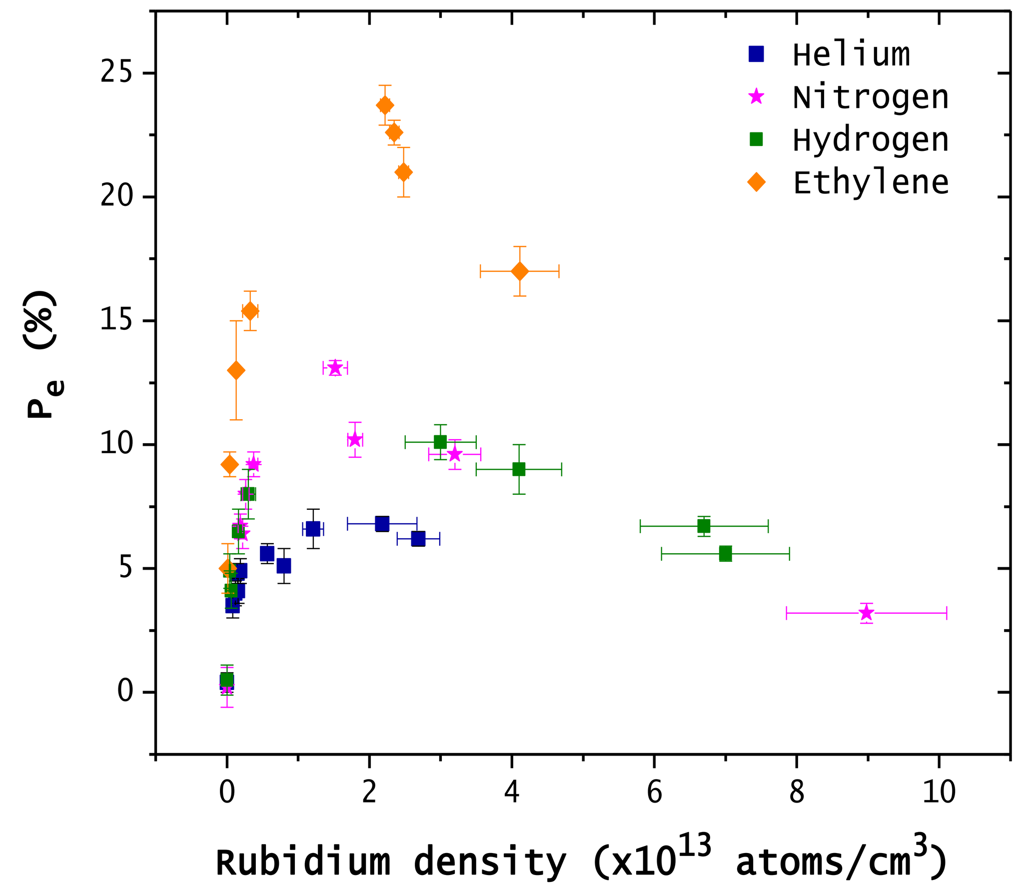

Fig. 2: Performance of the optically-pumped electron spin filter with different quenching gases. For each run, the gas pressure was ~200 mTorr, the pump wavelength 794.976 nm, and the pump spectral FWHM ~2 GHz. The energy of the electrons incident on the collision cell was ~3 eV.

In the optically-pumped spin filter, two processes are crucial to the production of polarized electrons:

- the degree of orientation of the rubidium vapor, and
- the thermalization of incident electrons (see Fig. 3).

Gas	Quenching cross-section (Å²)
Helium	~1
Nitrogen	58
Ethylene	139
Hydrogen	6

Ethylene (C_2H_4) yields electron beams with the highest polarization (see Fig. 2). It has the largest cross-section for causing excited rubidium atoms to decay non-radiatively [5]. It is thus the most effective at mitigating the depolarizing effects of radiation trapping [3] on the oriented alkali vapor. Also, in 1 Torr of gas, sub-excitation electrons thermalize 100 times faster in ethylene than in nitrogen [6].

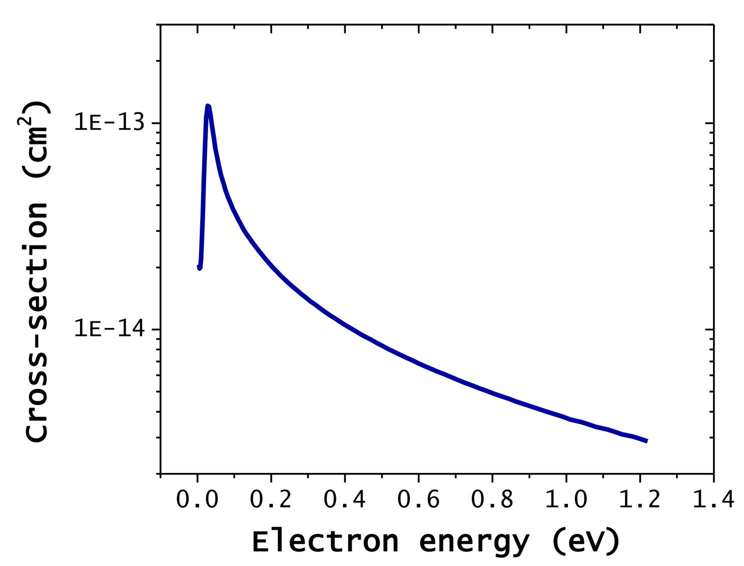

Fig. 3: Electron-Rb spin-exchange cross-section is largest for thermal electrons [7].

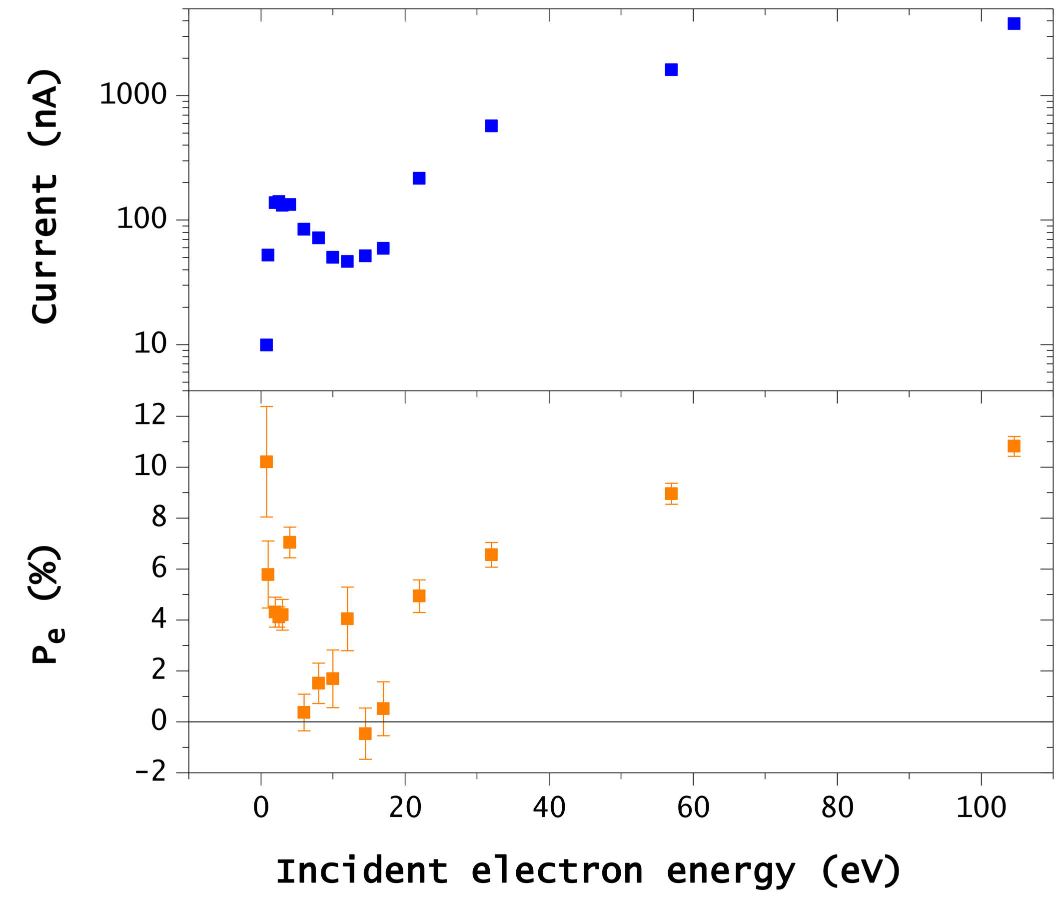

Fig. 4: The polarization is affected by the energy of the electrons incident on the collision cell. Here, the nitrogen pressure was ~130 mTorr, the rubidium density ~10^{13} atoms/cm^3, the pump wavelength 794.976 nm, and the pump spectral FWHM ~2 GHz.

Surprisingly, electrons incident on the collision cell with relatively high energy (~110 eV) produce beams with significant spin-polarization (see Fig. 4).

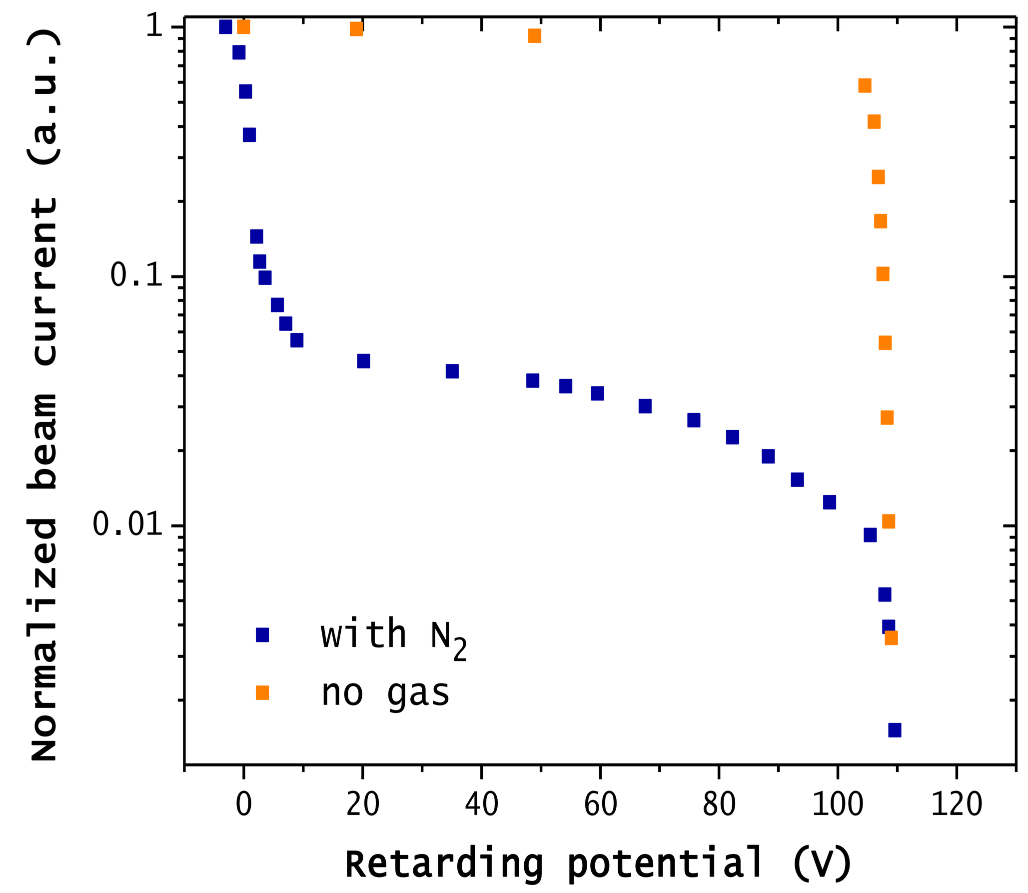

Fig. 5: Retarding field analysis of the beam resulting from ~110 eV incident electrons reveals that it consists mainly of very slow electrons. We speculate that numerous secondary electrons are produced from the ionization of nitrogen by the primary electrons. These slower secondary electrons have a high probability of undergoing spin-exchange collisions with oriented rubidium atoms.

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References

[1] T. J. Gay, *Advances in Atomic, Molecular, and Optical Physics*, chapter 4, Elsevier, 2009.
[2] H. Batelaan, A. S. Green, B. A. Hitt, and T. J. Gay, Phys. Rev. Lett. **82**, 4216 (1999).
[3] M.A. Rosenberry, J.P. Reyes, D. Tupa, and T.J. Gay, Phys. Rev. A **75**, 023401 (2007).
[4] L. Weller et al., J. Phys. B **44**, 195006 (2011); P. Siddons, Ph.D. thesis, University of Durham (2011).
[5] W. Happer, Rev. Mod. Phys. **44**, 169 (1972).
[6] L. G. Christophorou, K. S. Grant, and J. K. Baird, Chem. Phys. Lett. **30**, 104 (1975).
[7] I. I. Fabrikant, private communication (2011).