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A HIGH INTENSITY POLARIZED ELECTRON SOURCE FOR THE STANFORD LINEAR ACCELERATOR*

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ABSTRACT

Development of a high intensity, rapidly reversible, polarized electron source to serve as an injector for the Stanford Linear Accelerator is underway. Polarized electrons are obtained by illuminating negative electron affinity GaAs with circularly polarized light of wavelength corresponding to the band gap. The present status of the project is described. It is anticipated that this source will provide sufficient intensity of $\simeq$50% longitudinally polarized electrons to permit asymmetries on the order of 10^{-5} to be measured in reasonable periods of time.

INTRODUCTION

Interest in experiments with high energy polarized electron beams led the authors, during the past several years, to evaluate several polarized electron production techniques which showed promise as potential injectors for SLAC. In particular, photoemission from various magnetized materials,[1] field emission from tungsten needles coated with europium sulphide,[2] and the Fano effect in cesium[3,4] were extensively studied. In late 1974 we were about to begin work on a Fano effect source when measurements by Pierce et al. demonstrated that $\simeq$50% longitudinally polarized electrons could be readily extracted from gallium arsenide (GaAs).[5,6] This method had been proposed earlier by Garwin, Pierce, and Siegmann,[7] and somewhat later by Lampel and Weisbuch.[8] The prospects for obtaining large polarized electron currents and the considerable simplicity of the GaAs source led us to drop the Fano scheme, and in early 1975 we began the design and construction of a GaAs polarized electron injector for the linac.

Before discussing the details of the GaAs source, it is worthwhile to note several desirable characteristics for any polarized electron source. The frequently employed figure of merit, intensity times polarization squared, is relevant only where counting statistics are the limiting effect, and where neither the intensity nor the polarization is restricted by experimental conditions. When systematic effects are taken into consideration one may well be willing to exchange polarization for intensity to permit, for example, improved beam control and/or monitoring. Where very small asymmetries are to be measured, it is of considerable importance to maintain the source intensity, energy and energy spread, phase space, and steering upon polarization reversal. Rapid reversal, by optical rather than magnetic means, is a highly desirable feature as well. Much of our enthusiasm for the GaAs source stems from the excellent reversal characteristics we anticipate for the method.

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PRINCIPLES OF OPERATION

There are two fundamental aspects to the production of a polarized electron beam from GaAs. The first is the polarization mechanism. It is a consequence of the crystal symmetry of GaAs that transitions from the top of the normally filled valence band to the bottom of the normally unoccupied conduction band are like transitions from $j=3/2$ to $j=1/2$ states.[9] When induced by circularly polarized light, such transitions produce three times as many electron spins antiparallel to the photon spin as parallel to it, resulting in a polarization of 50%. The presence of an electron polarization of this magnitude induced by such interband optical pumping has been verified by observation of the circular polarization of the recombination radiation. These luminescense polarization measurements have indicated electron polarizations as large as 70% in GaAs.[10]

As electrons at the bottom of the conduction band in GaAs are normally bound by $\simeq 4$ eV, some means of emitting them without destroying their polarization is necessary. In GaAs this turns out to be a standard technique. By application of cesium and oxygen to a very clean GaAs surface, a negative electron affinity (NEA) surface is created. For GaAs treated this way, the bottom of the conduction band in the bulk material lies above the vacuum level, permitting electrons to leave the material from the bottom of the conduction band. While the nature of NEA surfaces is still a topic of current research, the processes necessary to produce them are empirically well defined.[11] Alternate deposition of approximately 1/2 monolayer coverages of Cs and O on very clean GaAs surfaces is what is required.

The NEA surface not only allows electrons to escape from the bottom of the conduction band, but it permits them to escape from deep ($\simeq 10^4$ Å) within the material, since their lifetime is limited only by recombination with the valence band holes. Without the dramatically lowered work function produced by the NEA surface, the hot electron scattering length ($\simeq 10^2$ Å) determines the depth from which electrons may escape. Thus the NEA surface provides a very high quantum efficiency. Photocurrents of 3 A/cm^2 have been extracted from NEA GaAs.[12] NEA surfaces are perhaps most familiar within the high energy physics community as the high efficiency dynodes in some contemporary photomultipliers. The subject is reviewed in references 13 and 14.

DESIGN CRITERIA

While our source design was based on the early results of Pierce *et al.*, their final results have been published, and we use these here.[15]

Figures 1 and 2 show the polarization observed by Pierce *et al.* as a function of photon energy for two different GaAs samples. Figure 3 displays the quantum efficiency typical of their samples (curve a), and compares this to an optimized GaAs cathode (curve b). These measurements were all done at 10°K. At higher temperatures polarizations are generally lower, but a result similar to that of figure 2 was obtained at $T \simeq 80^{\circ}$K. Two important

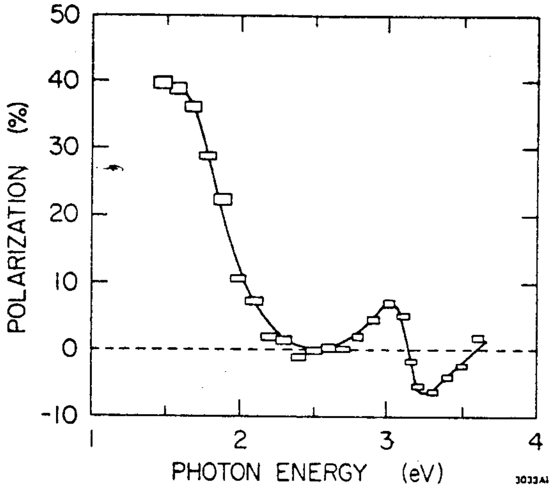

Fig. 1. Electron polarization measured from a sample of NEA GaAs.[15]

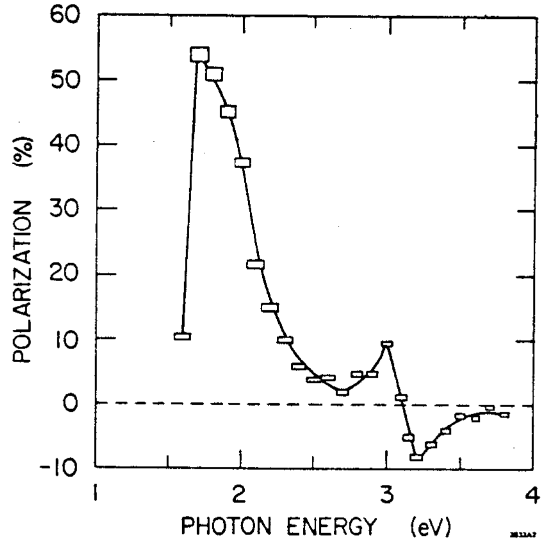

Fig. 2. Electron polarization measured from a sample of PEA GaAs.[15]

features of these results are readily apparent, viz.

i) different samples behave differently, both in maximum polarization and in the photon energy to achieve this maximum, and

ii) the quantum efficiencies were rather low.

Pierce et al. attribute the differences between figures 1 and 2 to slight differences in electron affinity. The sample of figure 1 presumably had a zero or slightly negative electron affinity, while the result in figure 2 can be explained by a slight positive electron affinity. The low quantum efficiencies were thought to be due to marginal vacuum at the time of cesiation (about 6×10^{-9} torr) and/or contamination from the cesiation system. The results are discussed in much greater detail in reference 15. While these results indicate that there is much to be studied, they do provide sufficient information to establish design criteria for a source. The various features of our source design are outlined briefly below.

1) GaAs gun assembly. Our polarized electron gun is very similar to the ordinary SLAC electron guns, with the conventional

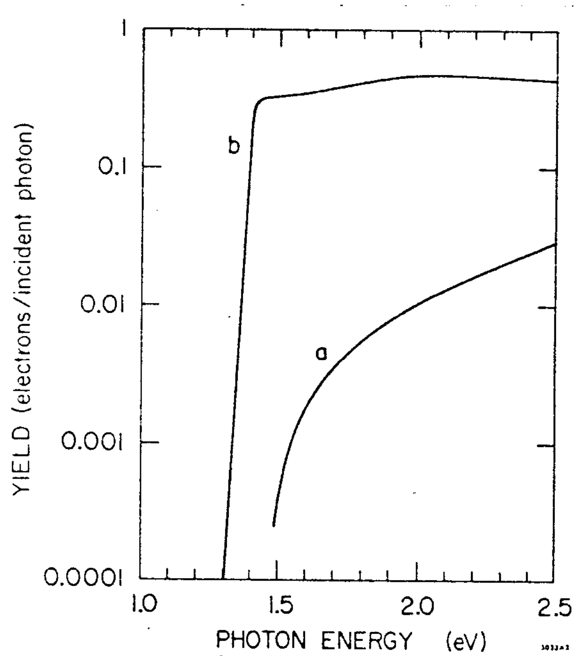

Fig. 3. Quantum efficiencies obtained by Pierce et al.,[15] curve a, and for an optimized GaAs cathode, curve b.

thermionic emitter replaced with a GaAs disk. Since it is necessary to prepare clean GaAs surfaces in situ, the GaAs disk may be heated from behind by an electron bombardment system. Such heating, to about 625°C, is a standard method of GaAs surface preparation prior to deposition of a NEA surface. The electron bombardment system is removed and replaced by a cooling arrangement which permits operation at LN_2 temperature when polarized electrons are to be delivered. With some modification, operation at LHe temperatures would be feasible. The cesiation and oxygenation system is built onto the gun, and the entire assembly may be isolated from the remainder of the system with a large high vacuum valve. The cesiation system uses pure cesium metal to avoid contamination problems. The complete gun assembly with the electron bombardment heater installed is shown in figure 4. The injection system we are building incorporates two complete gun assemblies, so that one may be delivering polarized electrons to the linac while the other undergoes surface cleaning and cesiation.

2) Vacuum system. The cleanliness required on the GaAs surface demands the use of a bakeable, hard metal sealed, ion pumped vacuum system. Partial pressures of offensive contaminants must be maintained at very low levels, hopefully in the 10^{-11} torr range in the vicinity of the GaAs surface. Properly prepared NEA surfaces show good quantum efficiencies over extended periods of time in systems such as ours, which is designed for continuous ultrahigh-vacuum operation.

3) Polarization measurement system. The beam polarization must be measured to assure that a successful polarized emitter has been prepared. To this end, we have constructed a Wien filter, to rotate the longitudinal spin to transverse, and a Mott scattering apparatus, to analyze this transverse polarization. The system is carefully designed to handle large beam current pulses. Europium activated CaF_2 scintillators, which are high temperature bakeable, are used to detect Mott scattered electrons. They are viewed by photomultipliers external to the vacuum system. While injection into the linac is normally done at 65 to 70 kV, the gun voltage can be raised to 100 kV, where Mott scattering is more easily done.

4) Laser system. The results of Pierce et al. clearly indicate the need for a variable wavelength photon source. Furthermore, while quantum efficiencies as large as in curve b of figure 3 would permit large electron currents from very modest light intensities (about 1 watt), the quantum efficiencies reported by Pierce et al. require several hundred watts of peak power to obtain the high currents we seek. SLAC can accelerate over 50 mA, and we hope to deliver over 10 mA with our source. A flashlamp pumped dye laser has been constructed to meet the optical requirements. The dye we are using initially, oxazine perchlorate, has an optimum lasing wavelength very near the peak polarization shown on figure 2, and can be tuned through about 300 Å. It is a straightforward matter to change to a different lasing dye. Efficient laser dyes are available throughout most of the red and near infrared spectral regions.

5) Polarization reversal. The dye laser provides linearly polarized light. Quarter wave retardation in a Pockels cell will be used to generate circularly polarized light. Presently, commercially available ring electrode

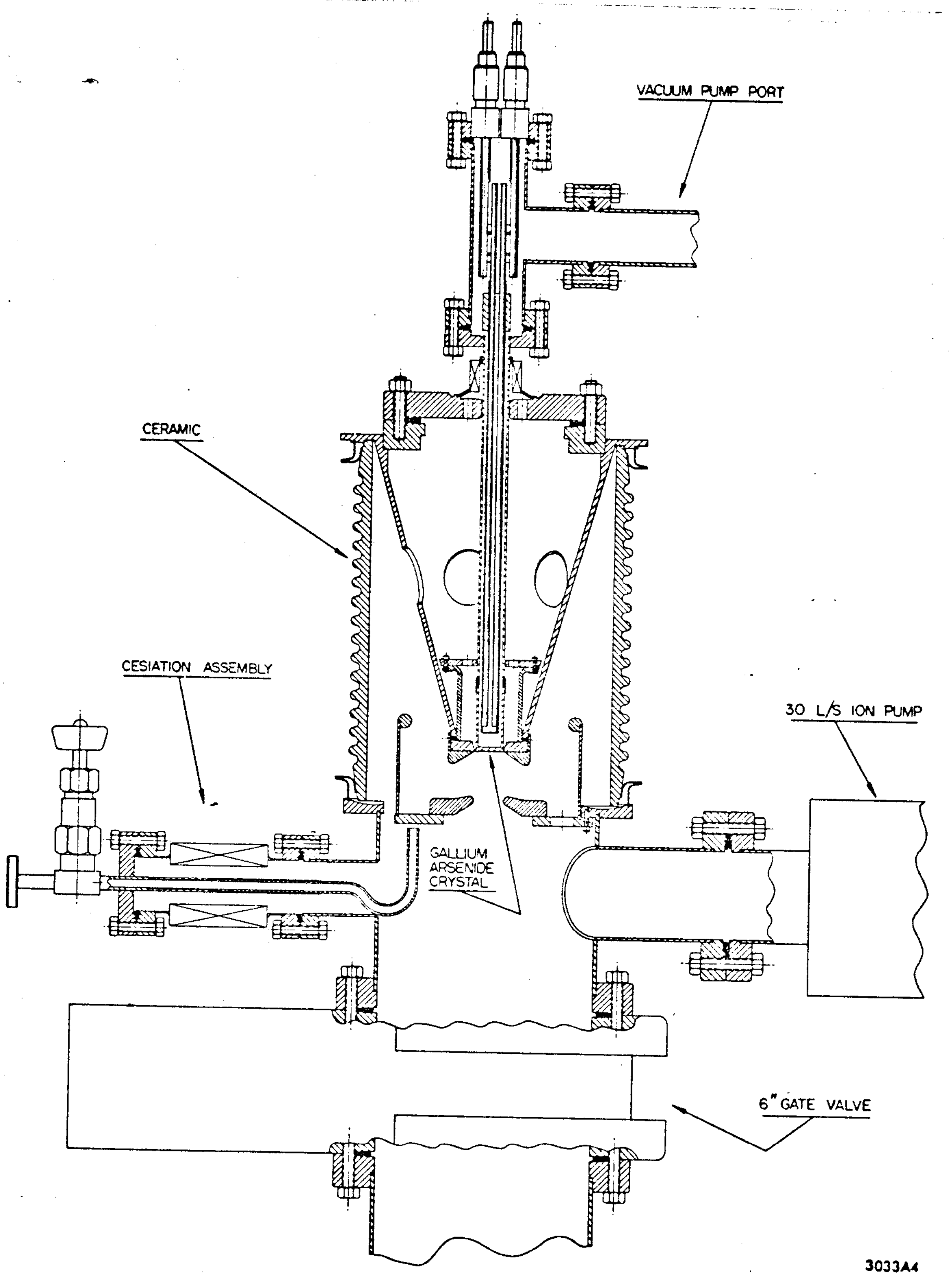

Fig. 4. View of the SLAC GaAs gun, with electron bombardment heater in place.

Pockels cells can provide a voltage tuneable optical retardation over a large aperture.[16] These cells can be electrically pulsed to quarter wave retardation at the repetition rate of the accelerator, allowing us to reverse the beam polarization randomly on a pulse to pulse basis. We anticipate that this feature will allow us to reduce systematic effects to a low level.

PRESENT STATUS OF THE PROJECT

The entire system, with only a single gun, is presently completely assembled, in an arrangement shown in figure 5. The GaAs gun is mounted vertically to avoid stresses in the large ceramic insulator. A 90^{o} bend is thus required to enter the accelerator. The complete system is presently assembled in a small laboratory for testing. Installation on the accelerator will occur shortly after successful laboratory demonstration of polarization and intensity.

The electron optical system has been studied with a beam from a hot filament rather than from the GaAs. Good transmissions were obtained between the 90^{o} bend magnet and the Mott scattering target. The dye laser has been operated at sufficient power to give a high current beam even from a low quantum efficiency surface, though this operation has been at low repetition rate. We decided to construct an all solid state pulsing system for the flashlamp, and this has given more problems than anticipated. However, the laser has been recently operated at over 80 pps, and we should be able to operate at the design rate of 180 pps shortly. The vacuum system has been fully baked once, and a pressure of 2×10^{-10} torr reached in the GaAs region. Mott scattering from unpolarized electrons has been observed at about the correct counting rate, indicating that the polarization analysis system is ready for more demanding work. Surface preparation and polarization studies are about to begin.

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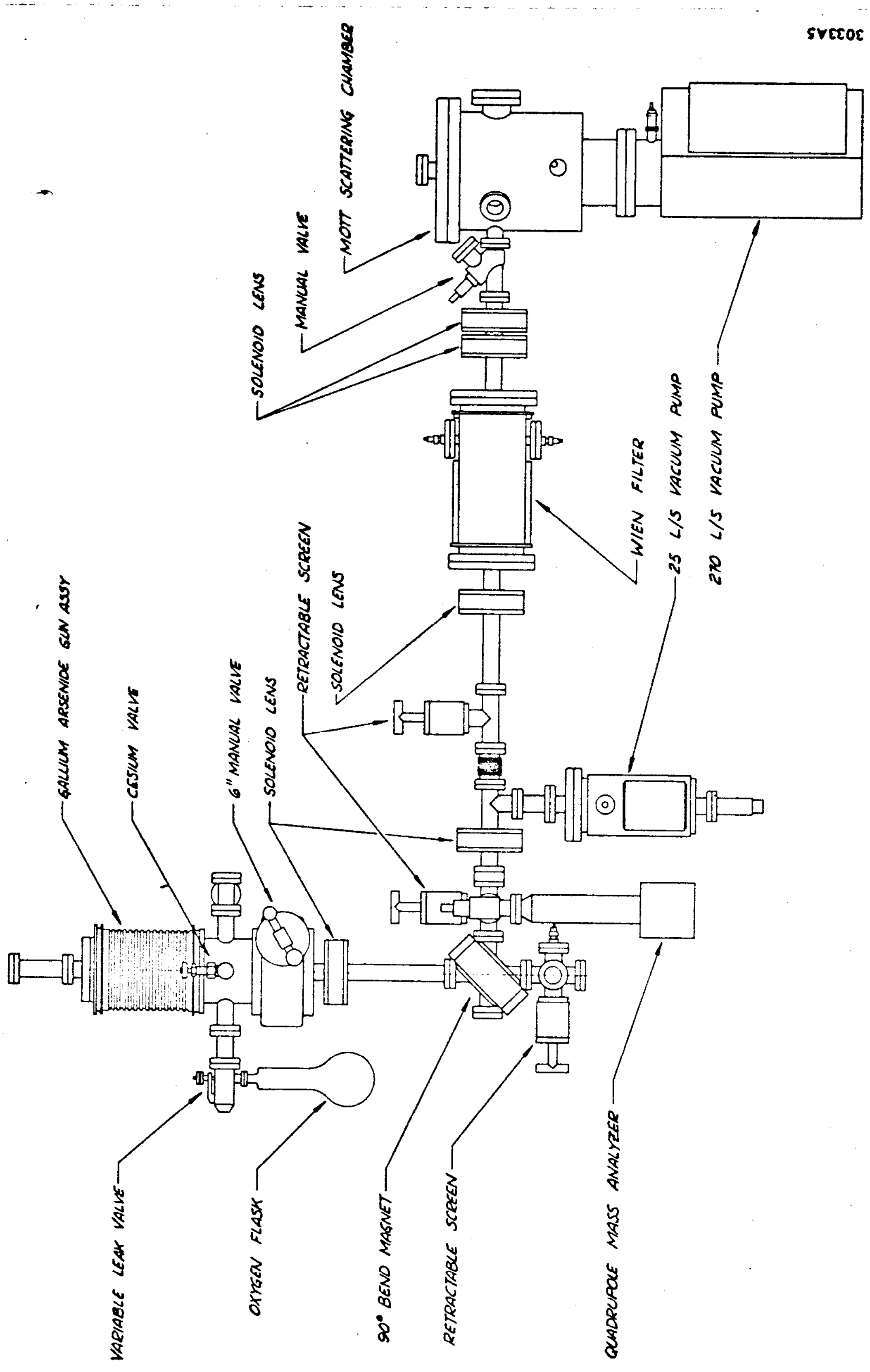

Fig. 5. Overall view of the SLAC polarized electron gun and polarization analysis system.