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A Derivative Standard for Polarimeter Calibration*

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Abstract

A long-standing problem in polarized electron physics is the lack of a traceable standard for calibrating electron spin polarimeters. While several polarimeters are absolutely calibrated to better than 2%, the typical instrument has an inherent accuracy no better than 10%. This variability among polarimeters makes it difficult to compare advances in polarized electron sources between laboratories. We have undertaken an effort to establish 100 nm thick molecular beam epitaxy grown GaAs(110) as a material which may be used as a derivative standard for calibrating systems possessing a solid state polarized electron source. The near–bandgap spin polarization of photoelectrons emitted from this material has been characterized for a variety of conditions and several laboratories which possess well calibrated polarimeters have measured the photoelectron polarization of cathodes cut from a common wafer. Despite instrumentation differences, the spread in the measurements is sufficiently small that this material may be used as a derivative calibration standard.

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ABSTRACT

A long-standing problem in polarized electron physics is the lack of a traceable standard for calibrating electron spin polarimeters. While several polarimeters are absolutely calibrated to better than 2%, the typical instrument has an inherent accuracy no better than 10%. This variability among polarimeters makes it difficult to compare advances in polarized electron sources between laboratories. We have undertaken an effort to establish 100 nm thick molecular beam epitaxy grown GaAs(110) as a material which may be used as a derivative standard for calibrating systems possessing a solid state polarized electron source. The near–bandgap spin polarization of photoelectrons emitted from this material has been characterized for a variety of conditions and several laboratories which possess well calibrated polarimeters have measured the photoelectron polarization of cathodes cut from a common wafer. Despite instrumentation differences, the spread in the measurements is sufficiently small that this material may be used as a derivative calibration standard.

I. INTRODUCTION

At present there is no electron spin polarization standard of the same sort as exists for many quantities, e.g., calibrated He leaks. While it can be stated that any one electron has a spin polarization of 100% along some unknown axis, this is not a very useful definition and is in fact incorrect as polarization is only definable for an ensemble. In itself, this lack of a standard would not present a problem provided it were possible *and* practical to independently calibrate individual polarimeters to a high degree of accuracy. While several polarimeters exist which are absolutely calibrated to 2%, this is not usually the case. Such inconstancy among polarimeters can make polarization measurements impossible to compare between different laboratories. In laboratories which perform complex transport of polarized electron beams in accelerating structures, undiscovered systematic errors in diagnostic polarimeters along the electron trajectory, particularly if of varying types, can contribute to erroneous conclusions on the quality of spin transport. Furthermore, as progress in high current solid state polarized electron sources pushes the polarization boundary toward the 100% upper limit, it is needful to establish the exact polarization, as this determines, among other things, the viability of pursuing polarization increasing schemes.

II. CHOICE OF MATERIAL

The choice for a standard usable in electron polarimeter calibration is obvious upon a careful examination of the requirements. For such a standard to be useful, it must either operate in existing polarized electron sources or be readily adaptable to them. It must be fairly independent of operating conditions and not drift (much) with time. It should be readily available in its final form, or should be easily made with minor perturbations in manufacturing resulting in no quantitative difference in performance. And ideally, it would be free or very cheap[1].

The ideal standard would be one whose properties could be predicted from first principles, e.g., a naturally occurring source of polarized electrons. One example of this type of source is ^{60}Co. However, such β-decay sources are weak and a usable signal level can only be attained by an increase in source density past a point where depolarization mechanisms begin to

alter the emitted electron spin polarization from the anticipated value[2]. This leaves only the possibility of creating a derivative standard, i.e., one whose properties may not currently be completely accurately predicted from first principles but which meets the rest of the criteria for a standard.

As the preponderance of polarized electron sources utilize photoemission from semiconductors such as GaAs and GaAsP, a derivative standard based on one of these materials is a logical choice. In order to maximize polarization without compromising performance, a layered structure with an active layer of 100 nm was adopted[3]. A diagram of the source material appears in Figure 1. The $Al_{0.3}Ga_{0.7}As$ layer, which has a lattice constant sufficiently close to that of bulk GaAs for unstrained growth, acts to impose an energy barrier to emission

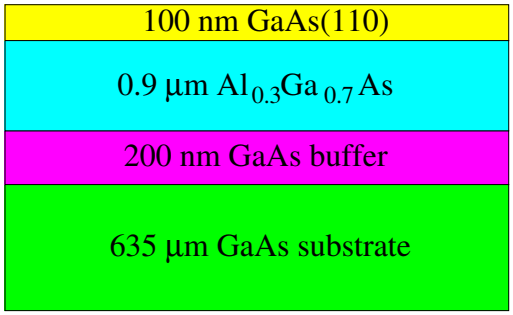

Figure 1: Schematic of standard cathode material

from the underlying GaAs, hence photoemission using light with energy less than 1.85 eV results in photoelectrons from only the top 100 nm of material. The Be dopant concentration was set at $5x10^{18}/cm^3$ so as to enable creation of a high quality negative electron affinity surface while minimizing depolarizing effects[4].

III. MATERIAL QUALIFICATION

Prior to distribution, material from the 3" diameter wafers[5] was extensively tested in the Cathode Test Laboratory (CTL) at SLAC[6]. Characterization included uniformity of response across the wafer and performance of the material under a variety of conditions. Typical polarization and quantum efficiency (QE) performance data appear in Figure 2. Polarization data are to be viewed for relative values only. QE data from bulk GaAs is shown for comparison. In the region of interest, around 850 nm, the difference in QE between the two is only a factor of two. This is especially important for those measurements taking place in polarimeters with low efficiencies.

The wafer map of the samples tested in the various laboratories appears in Figure 3. Six of the samples labeled "PEGGY" were measured in the CTL at SLAC. The regularity of response in the polarization at a given wavelength and QE, which is a reflection of both cathode uniformity and systematic drifts in the CTL was within 2% relative.

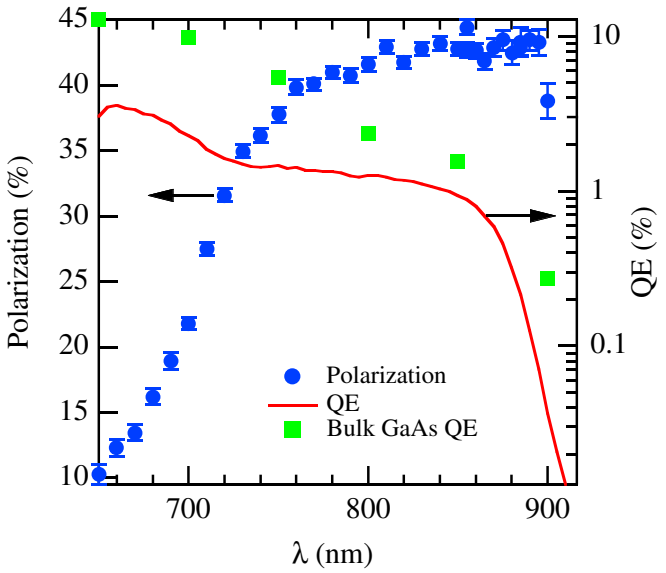

Figure 2: Polarization and QE of standard material.Bulk GaAs QE is shown for comparison. Note that in the region of highest polarization the QE of the bulk GaAs is only a factor of two greater than that of the standard material.

As conditions within source chambers differ from laboratory to laboratory, it was necessary to quantify the change in polarization as a function of QE. One such set of data appears in Figure 4. As can be readily seen, the increase in polarization upon QE decay is rather small. From these observations, we chose a measurement wavelength (841 nm) that would yield a high QE, a maximum in the polarization and little change in polarization as the QE decays.

It was also necessary to determine the effects of different techniques for introducing the cathodes into vacuum, e.g., loadlock versus baking the cathode within the source chamber. Sample treatment differences were tested by baking one of the "PEGGY" samples in the loadlock of the CTL test system. No differences not accounted for by a slightly different QE from the unbaked samples introduced through the loadlock were seen in the polarization.

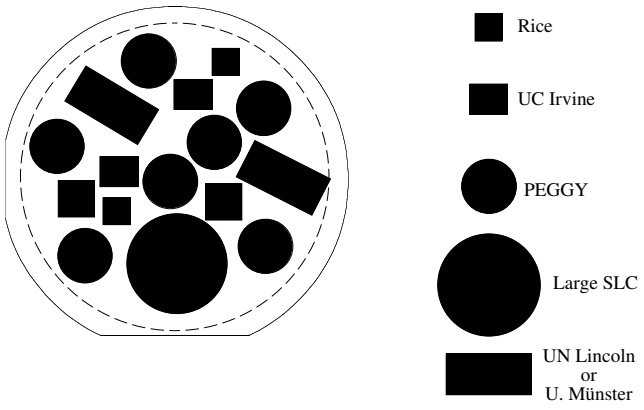

Figure 3: The location of the samples tested in the CTL and samples for measurement in highly accurate polarimeters.

The various processes responsible for QE decay were tested in their effects on the polarization. One sample (shown in Figure 4) was permitted to decay naturally for nearly one month. Another had its QE dropped by the admission of NF_3. A third had its QE decay rate accelerated by allowing the emitted electrons to impact the chamber walls, bringing about electron stimulated desorption of common background gasses. In all of these tests, no difference was seen in the polarization dependence on the QE at 841 nm between samples with QE decays accelerated by the different techniques.

While some change in the polarization at 841 nm is evident as the QE decays, it is sufficiently small that it does not appear clearly above the statistical scatter in the data. The cumulative data allow us to assign a preliminary polarization value of 43.4±0.86% for QE ranging from 1.2–0.009%. In other words, the polarization is constant to within a relative value of 2%, the degree of stability we required from our standard.

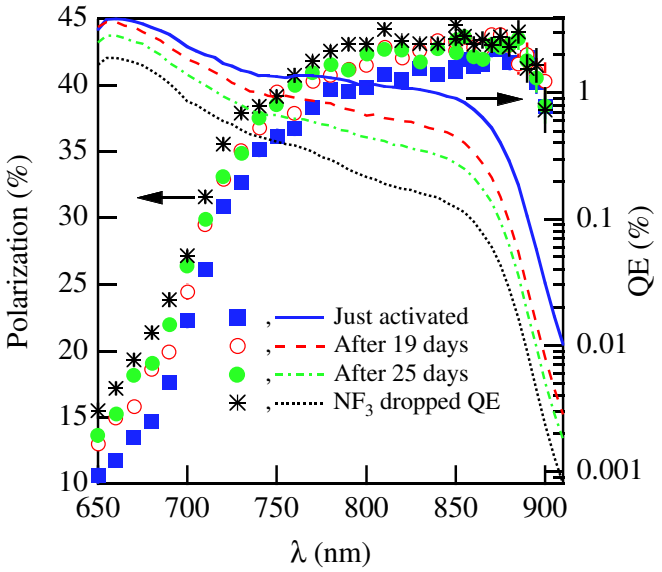

Figure 4: Polarization and QE of standard material as QE decays. The last data set was acquired by dosing the sample with NF_3. The source lifetime (e-fold time) was 26 days.

IV. POLARIMETER BESTIARY

The polarimeters used in this work fall into two categories, Mott[2] and optical[7]. The Mott polarimeter operates by measurement of a back–scattering asymmetry in the electrons impacting a high atomic mass film. Mott polarimeters may be self calibrated, but great accuracy can be achieved only with much difficulty[8]. Two of the participating institutions utilize Mott polarimeters calibrated through novel techniques. At UC, Irvine, a pseudo-double scattering technique is used to achieve an accuracy within ±2% in a 120 keV Mott polarimeter[9]. Rice University, on the other hand, pioneered the use of surface Penning ionization coupled with an accurate He metastable polarization measurement to calibrate a 20 keV retarding field Mott polarimeter to an accuracy within 3%[10]. Optical polarimeters, which operate on the principle of measurement of the polarization of de-excitation light from noble gas atoms after electron collision at near–threshold energies, are essentially self calibrating.

V. PRELIMINARY RESULTS AND OUTLOOK

At the time of this writing, measurements have been undertaken at three of the four institutions participating in measurements utilizing highly accurate polarimeters. The measurements at UC, Irvine, which are completed, yielded P = 42.69±0.92% at a QE of 0.38% and P = 44.66±0.94% at a QE of 0.08%. Measurements at Rice using an 807 nm laser yielded P = 40.0±2.5% at a QE ≈ 0.1%. The photocathodes at Rice and UC, Irvine were activated with O_2 instead of NF_3 indicating that the photoelectron polarization is not sensitive to the activation process. Data from UN, Lincoln are still too preliminary to be cited and measurements at the University of Münster have not yet taken place. These initial results show good promise that we may quote a final number for the polarization with an error ≤ 5% relative.

VI. REFERENCES

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