1-1-1990

In Situ Hall-Effect System for Real-Time Electron-Irradiation Studies

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Repository Citation

Ziebro, B. S., Look, D. C., Hemsky, J. W., & Rice, J. (1990). *In Situ* Hall-Effect System for Real-Time Electron-Irradiation Studies. *Review of Scientific Instruments, 61* (1), 192-194.
https://corescholar.libraries.wright.edu/physics/174

For FL 2000/3000 systems already in service, however, replacement of the original cuvette assembly with redesigned units can be quite costly. In lieu of replacement, Teflon coating provides a quick and economical solution.

We would like to thank Martin Mikus of Lambda-Physik and Richard Steppel of Exciton for helpful discussions on possible causes of dye decomposition.

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In situ Hall-effect system for real-time electron-irradiation studies

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(Received 17 July 1989; accepted for publication 25 September 1989)

A unique system capable of taking *in situ* Hall-effect measurements during electron irradiation has been developed. The key element is a small, powerful rare-earth magnet. Measurements can be taken while the electron beam is on, resulting in a considerable time savings and eliminating problems associated with mounting and demounting the sample. High resolution electron concentration and mobility versus fluence data are quickly and easily obtained, making possible detailed defect production rate studies as functions of energy and flux.

The study of irradiation damage to semiconducting materials like GaAs has received much attention over the last few decades, because defects produced by the irradiation can lead to significant changes in the electrical and optical properties of the materials.[1] Perhaps the most useful technique for investigating the electrical properties of semiconductors is the Hall effect; in this paper we describe a unique system capable of taking *in situ*, real-time Hall-effect measurements in an electron-irradiation environment. The analysis is simplified if the current applied for the Hall-effect measurements is much larger than the electron-beam current.

The ability to take measurements while the beam is on has several distinct advantages. The first is a considerable savings in time, since the sample does not need to be demounted and then remounted between irradiation steps. This allows very detailed carrier concentration n and mobility μ data to be gathered as a function of dose ϕ and flux $d\phi/dt$. Furthermore, removal and remounting of the sample often results in contact smearing, or surface contamination, so that small changes in the electrical properties are masked. A second advantage is that the electron-beam current hitting the sample can be measured directly, simply by turning off the Hall-effect current source, and passing the electron-beam current to ground through the Hall-effect ammeter; thus, irradiation currents and doses can be monitored continuously and determined more accurately. Of course, any electrons passing completely through the sample, and thus entering ground through the sample mounting flange, must be accounted for.

The experimental setup consists of an aluminum tube, a Faraday-cup assembly which slides into the tube, and an automated Hall-effect system with a special, small magnet. The tube is placed at the beam exit of a van de Graaff accelerator; the electrons exit the accelerator vacuum and enter the tube via a $\frac{1}{2}$-in.-diam aluminum window. The tube has an input valve and exit valve to allow for inert gas flow in the assembly, if desired.

The Faraday-cup assembly, shown in Fig. 1, has a back

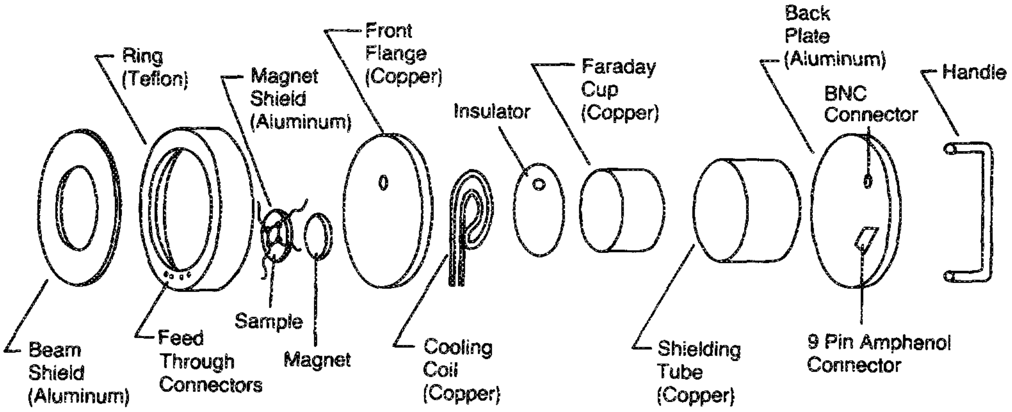

FIG. 1. A breakdown of the Faraday-cup assembly used in this work.

plate onto which is fitted a handle, a 9-pin amphenol connector, and a BNC connector. The Faraday cup is joined to the BNC connector by a wire, and then a cable runs from the BNC to a current integrator. Thus, we have two distinct ways to determine beam current and dose, i.e., by using the Faraday cup or the sample itself. The amphenol connector is used to join the four wires from the sample to the Hall-effect electronics. A grounded copper tube surrounds the Faraday cup and is soldered to the 3⅞-in.-diam front flange. The electron beam enters the Faraday cup through a 0.28-cm^2 hole in the flange. The cup is insulated from the back of the flange with 0.2-in.-thick teflon.

Onto the front flange we have placed a samarium-cobalt magnet[2] of diameter 1 in. and thickness ⅜ in. for determining the Hall coefficient. Protecting the magnet is an aluminum shield, of thickness 0.1 in., onto which the samples are placed; the field strength near the center of the magnet-shield assembly is 1.6 kG. The sample position is the same distance from the center of the front flange as is the hole in the Faraday cup; thus, the sample and hole experience the same beam current. The sample temperature is kept near room temperature during irradiation by a water cooling tube soldered onto the back side of the front flange.

The front flange is surrounded by a teflon ring which allows the unit to slide snugly into the chamber. Placed into the teflon ring are four feed-through connectors, which connect the thin unshielded wires leading from the sample to shielded sample wires leading to the amphenol connector. Finally, there is an aluminum shield to protect the teflon ring from excessive beam exposure.

The effects of placing a magnet directly in the beam path were examined both theoretically and experimentally. Theoretically, we used the relativistically invariant form of the Lorentz force equation to show that the total deflection, in the region of the small Faraday hole, was a counterclockwise movement of about 0.2 mm, almost negligible. To verify this conclusion, a circular piece of clear lexan, 0.020 in. thick, was placed on the aluminum shield and irradiated with a dose of $7.8 \times 10^{12}\ \text{cm}^{-2}$. Transmission data, at 0.7 μm, were then taken on this pattern and are shown in Fig. 2. This experiment was carried out both with and without the magnet present on the flange. As can be seen, the pattern shows very little change upon placing the magnet in the indicated position. More importantly, the sample and Faraday hole experience nearly identical beam intensity in either case.

Hall-effect data were obtained by using a standard DCL-1 system[3] with a Prema Mod. 2024 programmable scanner.[4] The system is designed to use the van der Pauw switching technique for measuring the Hall coefficient, thus eliminating the need for magnetic field reversal (which, of

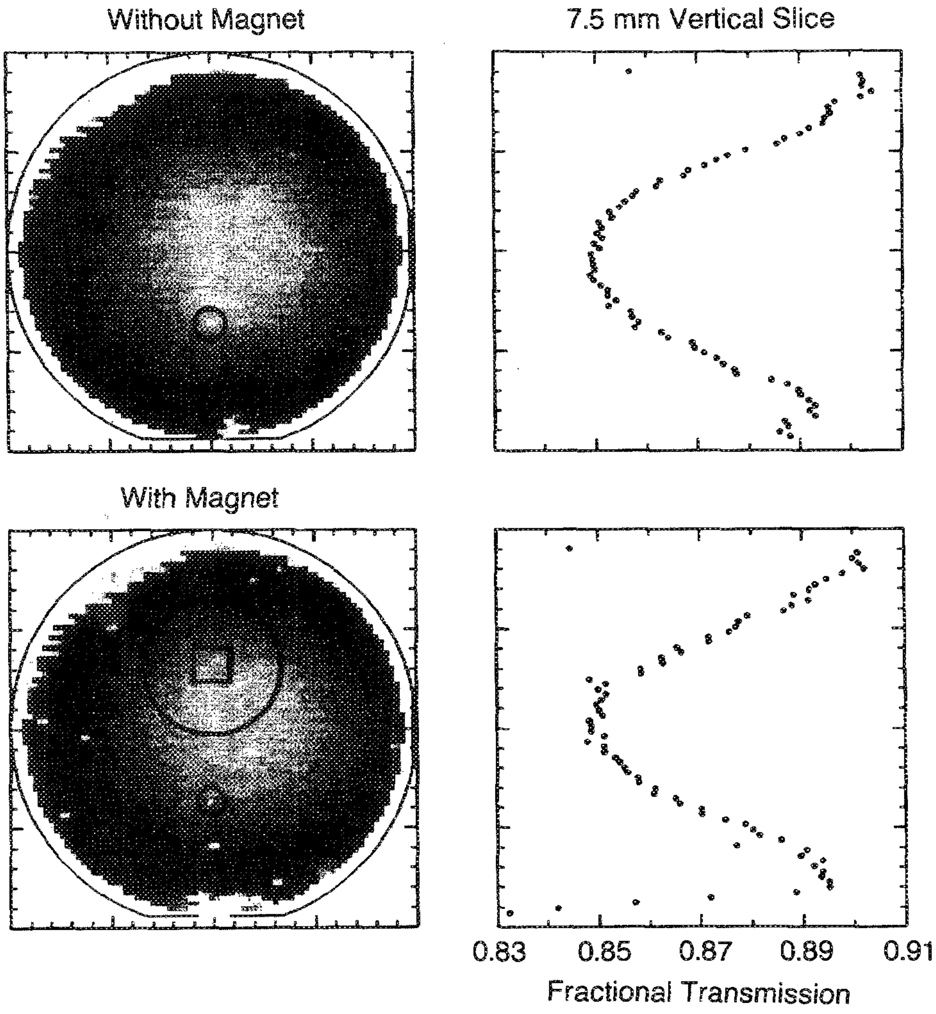

FIG. 2. Transmission maps (at 0.7 μm) of thin lexan sheet exposed to the electron beam. Low transmission corresponds to high beam intensity. The actual color of the irradiated areas was yellow. The Hall-effect magnet and Faraday-cup current hole silhouettes are superimposed on the maps.

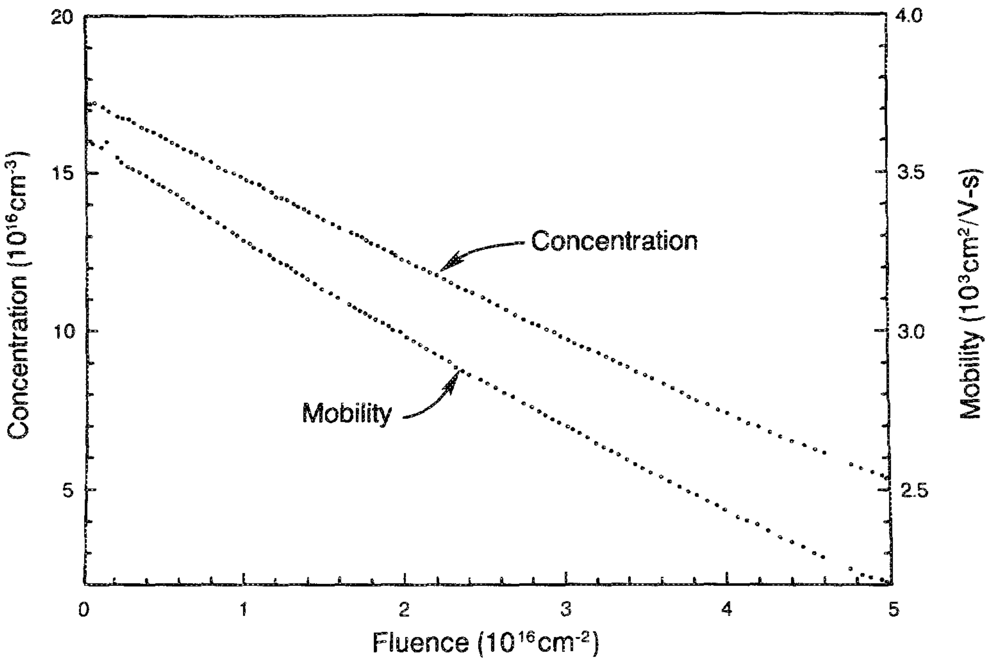

FIG. 3. Carrier concentration and mobility versus fluence data for a 10-μm MBE GaAs layer exposed to 1-MeV electrons at a current density of 2 μA/cm^2.

course, would be difficult here). Also, in a magnetic field of this strength (1.6 kG) magnetoresistance effects in GaAs and most other semiconductors are negligible, and resistivity measurements may be taken in the presence of the field.

The utility of the *in situ* Hall-effect system is demonstrated by the high-resolution n and μ versus ϕ data of Fig. 3. The electron beam had an energy of 1 MeV and a current density of 2 μA/cm^2. The sample shown here, a molecular-beam epitaxial GaAs layer 10 μm thick on a 600 μm semi-insulating GaAs substrate, had an electron concentration of 1.7×10^{17} cm^{-3}, typical of that used for GaAs metal-semiconductor field effect transistors (MESFET's). Note, however, that the sample thickness was much higher than that used in normal MESFET's in order to minimize surface and interface depletion corrections in the carrier concentration calculations.[5] The decrease of n with increasing ϕ is due to the net production rate of acceptors over donors,[1] and the decrease of μ is due to the increase of total ionized scattering centers. The system described here should further be very useful in investigating flux (current) dependence of the production rate, since the current can be changed at will while data are being gathered. Also, energy can easily be varied during the run. Finally, the very interesting phenomenon of type-conversion can be conveniently studied with this apparatus.[6]

We wish to thank T. A. Cooper for help with sample preparation, M. Mier and J. Sizelove, for the transmission data shown in Fig. 2, E. Stutz and K. Evans for growing the MBE sample, M. Andrews and D. Thomas for strong encouragement and assistance, and R. Heil for typing the manuscript. The work of BSZ was supported under the State of Ohio Research Challenge Grant 5306. Also, we gratefully acknowledge an equipment loan from the Electronic Technology Laboratory, Wright-Patterson Air Force Base, Ohio.

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