On-Wafer Hall-Effect Measurement System

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A novel system capable of making on-wafer Hall-effect measurements of a patterned wafer during the fabrication sequence has been developed. A flat, powerful rare-earth magnet provides the magnetic field required. The wafer need only have van der Pauw patterns available for on-wafer measurement capability. Measurement of room temperature Hall mobility can quickly and easily be obtained, making possible detailed study of carrier concentration and mobility variations during wafer fabrication.

Measurements of conducting layer mobility and carrier concentration are important and useful parameters in the design and modeling of field effect devices. Designers are able to use this information to more effectively model device designs for improved performance and the information can provide a guide to process engineers for modifications aimed at improved process uniformity. Methods that rely on *C-V* and *I-V* measurements of test structures have been developed to obtain carrier mobility and concentration. These methods require careful attention to measurement technique and are difficult to accurately implement. The measurement technique described here uses simple resistance measurements of a Greek cross structure defined in the active layer material and incorporates a flat, samarium-cobalt magnet[1] of 2.5 in. diameter, placed under the wafer sample to provide a magnetic field for Hall-effect measurements. This method permits nondestructive characterization of whole or partial wafers with resolution limited solely by the number of defined test patterns. A semiautomatic prober (Electroglas 2000 series) coupled to a parametric test system (Keithley 450) permits rapid, accurate measurement of test sites.

The test pattern used to demonstrate the technique is the usual Greek-cross structure typically employed for sheet resistance measurements. It is repeated every 2.0× 2.5 mm on the wafer. Van der Pauw resistance[2] and Hall-effect measurements are performed on this structure in the usual manner, producing the sheet resistance and the sheet Hall coefficient of the conducting layer. The magnetic field (see Fig. 1) is presently measured at the same physical location as the test structure and stored. It would be possible to map the field of the magnet once into digital memory for routine testing rather than each time as is currently done. The equations used for the technique are given below:

$$\rho_s = \frac{\rho}{t} = \frac{\pi}{\ln 2}\,\frac{R_{43,12} + R_{23,14}}{2}\ \Omega/\text{square}, \tag{1}$$

$$R_{Hs} = \frac{R_H}{t} = \frac{10^8}{B}\,\frac{|R_{42,31}| + |R_{13,24}|}{2}\ \text{cm}^2/\text{C}, \tag{2}$$

$$\mu_H = \frac{R_H/t}{\rho/t} = \frac{R_{Hs}}{\rho_s}\ \text{cm}^2/\text{V s}. \tag{3}$$

In reference to the test structure pattern inset in Figs. 2 and 3 and the above equations, the parameter $R_{ij,kl}$ denotes resistance measured with current flowing from contact i to j and voltage measured between contact k and l. Here, the contacts are numbered counterclockwise, beginning at upper left. Also, B is in Gauss and t in cm, and we are assuming a unity Hall factor. In addition to the Hall mobility (μ_H), the sheet-Hall concentration of the active layer can be calculated from $n_s = 1/eR_{Hs}$. This parameter, after depletion corrections, is useful for determination of the activation efficiency of ion implanted layers.[3]

The flat, rare earth magnet was measured initially with 1 mm resolution to ascertain the uniformity of the field strength and its positional dependence. The resulting map

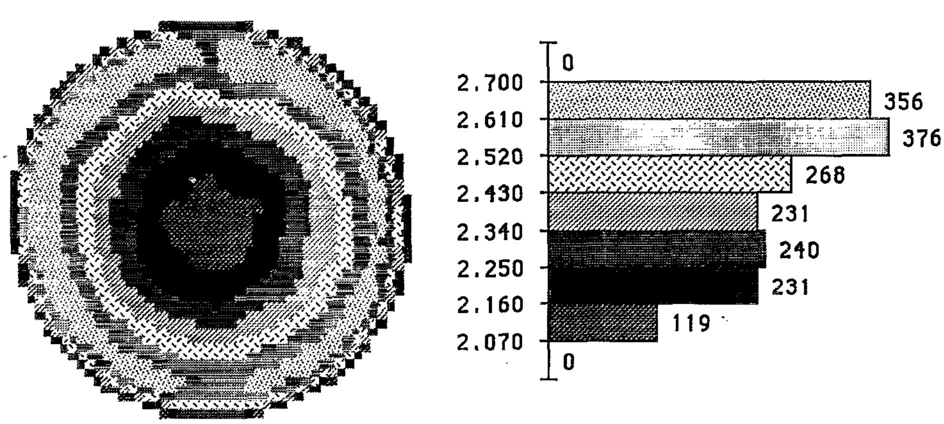

FIG. 1. Magnetic field strength (in kilogauss) at 1 mm resolution. Sample mean is 2.435 with a standard deviation of 0.168 (6.9%). The numbers on the right indicate the number of values within each bin.

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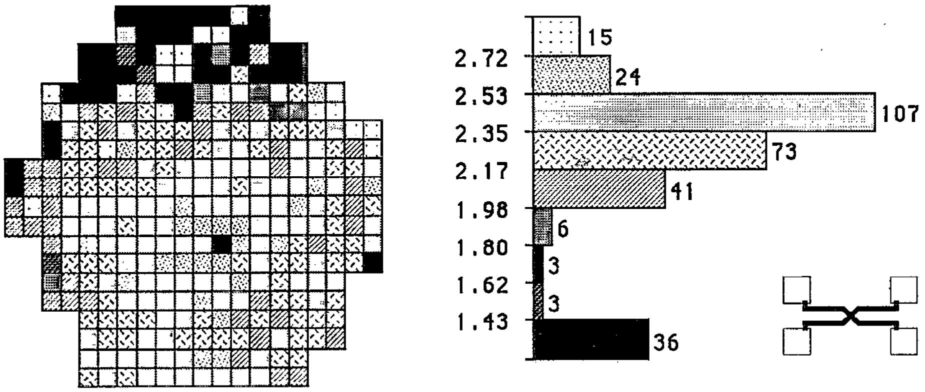

FIG. 2. Sheet-Hall concentration (in 10^{12} electrons/cm^2). Sample mean, excluding upper and lower bins, is 2.32 with a standard deviation of 0.2 (8.6%). Test structure pattern is inset.

is shown in Fig. 1. In general, there is a radial dependence of magnetic field strength, producing nearly concentric annular rings relative to the center of the magnet. The center of the magnet has the lowest value of field strength with the area near the edge having the highest. The field strength varied $\pm 10\%$ over most of the magnet surface. A 2 in. ion implanted GaAs wafer was used to demonstrate the usefulness of this measurement technique. The test structure was probed using an Electroglas 2001X prober coupled to a Keithley 450 parametric test station. Total test time for 308 sites was 64 min. This time included error checking routines for linearity of the measurement, a check for nonohmic contacts, and use of an external microvoltmeter for very accurate measurement of resistance structures. The test time could be considerably reduced by using the test stations' internal voltmeter, commonly employed for field effect transistor (FET) measurements, to measure the sheet resistance pattern. A map of the measured wafer sheet-Hall concentration and Hall mobility are shown in Figs. 2 and 3. The mean and standard deviation of the binned values of each parameter are listed in the figure captions.

A physics based transistor process simulation program, GATES[4] (gallium arsenide transistor engineering simulator), was used for comparison of predicted versus measured Hall quantities. The wafer was implanted with a dose of ^{28}Si at 5×10^{12} electrons/cm^2 at 100 keV. The simulation was run with implant activation adjusted to provide agreement with the measured active layer sheet resistance from the Greek cross structure and the unrecessed transistor saturation current as measured on a 200 μm single finger FET. The mobility and sheet carrier concentration were deduced from these data. The results of this simulation indicated an implant activation between 73% and 76% with an average sheet concentration of 2.52 $\times10^{12}$ electrons/cm^2, and average active layer mobility of 4500 cm^2/V s. These results agree quite favorably with the mean sheet-Hall concentration of 2.3×10^{12} electrons/cm^2, and mean Hall mobility of 4454 cm^2/V s derived from the data in Figs. 2 and 3. The Hall measurements are, of course, more accurate since they constitute a more direct measurement of mobility and carrier concentration. In conclusion, it appears that our on wafer Hall-effect system works quite well and gives information not easily obtainable in the past. To improve the application of this measurement capability and permit its incorporation as a routine in-process test, a vacuum chuck mounted on a flat magnet has been constructed and initial maps of the magnet's field strength have been made. These improvements will permit Hall-effect measurements on any 2 in. wafer with Greek cross test structures, without special operator handling. Upgrading to larger wafers would require correspondingly larger magnets, which are available from Permag Corp.[1]

[1] Permag Corp. 2960 South Avenue, Toledo, OH.
[2] L. J. Van der Pauw, Philips Res. Rep. **13**, 1 (1958).
[3] D. C. Look, J. Appl. Phys. **66**, 2420 (1989).
[4] Gateway Modeling, Inc. 1604 East River Terrace, Minneapolis, MN.

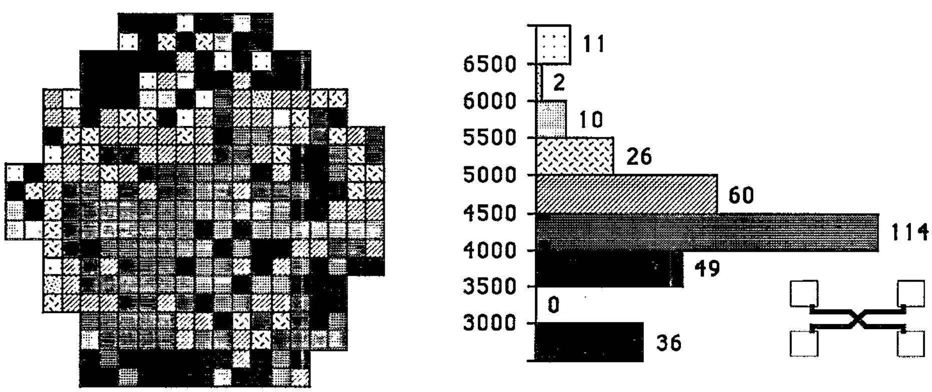

FIG. 3. Hall mobility (in cm^2/V s). Sample mean, excluding upper and lower bins, is 4454 with a standard deviation of 513 (11.5%). Test structure pattern is inset.