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Precision of Micro Hall Effect Measurements in Scribe Line Test Pads

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INTRODUCTION

Precise metrology for monitoring electrical properties in semiconductor manufacturing is of paramount importance [1]. However, obtaining high precision on measurements of electrical properties is difficult in the three dimensional device geometries of semiconductor devices being fabricated today. For nano-structured materials, electrical measurements become increasingly dependent on geometrical variability such as line width and roughness, thus decreasing the measurement precision on the electrical properties of the materials under test. In order to monitor electrical properties independent of geometrical effects, micro four-point probe sheet resistance measurements [2] or micro Hall effect measurements [3] in small scribe line test pads may still be the most practical solution, in combination with metrology, for precise measurement of nano-structure dimensions.

In micro Hall effect measurements, both sheet resistance, sheet carrier density and carrier mobility are measured simultaneously. The method relies on placing four electrodes on a thin conducting sheet in proximity of an insulating boundary with a magnetic field perpendicular to the sample surface. The measured four-point resistance includes both Hall effect and Corbino effect. Since the first description [3], several improvements have been made to reduce measurement time and increase measurement precision by application of geometrical error suppression methods, e.g., the far separation method [4], the short separation method [5], and most recently, the single-engage method using equidistant [6] or asymmetric electrodes [7], respectively.

In a previous numerical study, the single-engage method using equidistant electrodes was evaluated for semi-infinite sheets and square samples [8]. Here, we evaluate the precision of the single engage method on small rectangular pads using asymmetric electrodes [7]. Asymmetric electrodes can increase the signal to noise ratio by up to an order of magnitude. The assessment of measurement precision is performed numerically and will be supported experimentally by repeatability measurements on small test pads of B-doped SiGe. In this study, we examine how the size of a rectangular test pad affects the relative standard deviation of the extracted parameters. Furthermore, it is investigated whether the relative standard deviations can be improved by placing the probe closer to the edge of the pads.

MICRO HALL EFFECT MEASUREMENTS

Micro Hall effect measurements are performed by placing a micro 7-point probe (M7PP) parallel and close to an insulating boundary, cf. Fig. 1, and applying a magnetic field (B_z) perpendicular to the sample surface. A series of four-point resistance values are recorded using different combinations of probe pins for current and voltage electrodes. Utilizing that the resistance measured with different combinations of probes depend differently on the distance to the insulating boundary (y_0), it is possible to estimate this distance. Once the distance to the boundary is known it is possible to determine the sheet resistance (R_0) and the Hall resistance (R_H) of the sample. From these two parameters the Hall mobility (μ_H) can be calculated as, $\mu_H = R_H/(R_0 Z B_z)$, where Z is the polarity of the charge carrier. The Hall sheet carrier density (N_{HS}) can be calculated as $N_{HS} = ZB_z/(qR_H)$, where q is the unit charge [3].

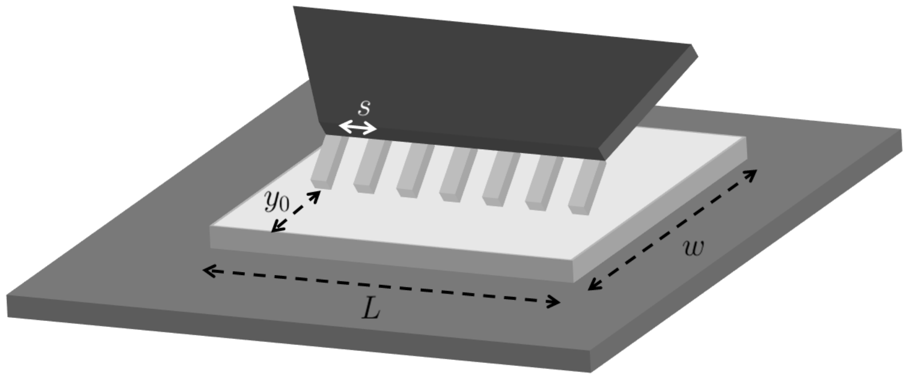

FIGURE 1. Illustration of an M7PP with 7 pins, separated by pitch s, placed on a rectangular test pad with dimensions $L \times w$, at a distance y_0 from the insulating boundary.

SIMULATION OF MEASUREMENT ERRORS

To assess the measurement precision on test pads of different sizes, Monte Carlo simulations including some of the most common sources of error, were performed. The main sources of error in micro Hall effect measurements are position errors and electrical noise. Static probe position errors are defined as displacement of contact points of the probe pins away from their ideal, equidistant positions. These position errors can be in-line and off-line. Static position errors are constant throughout a single engage, whilst using different configurations, but may change from engage to engage. Static in-line position errors can be suppressed using dual configuration measurements [4]. Further techniques for position error suppression are described in [5]. Electrical noise in the measurements will appear as random fluctuations and is described by the Signal-to-Noise-Ratio, SNR. The parameter most affected by the electrical SNR is the Hall signal, since this signal appears as a difference between two resistance measurements each with electrical noise proportional to the measured resistance.

In particular, in- and off-line errors, as well as electrical noise, were implemented in the measurement simulations. The in- and off-line errors were normally distributed with a standard deviation of $\sigma_{x,y} = 0.2s$, where s is the probe pitch, and applied to each pin in the probe. Furthermore, a SNR of 3000 was chosen, to account for electrical noise. The magnitude of these errors is based on experience, as well as previous simulations [8]. The Monte Carlo simulations were run 500 times for each parameter varied (w, y_0), using a 10 µm pitch M7PP. The results will be discussed in the following section.

RESULTS AND DISCUSSION

The results from the Monte Carlo simulations are displayed in Figs. 2 and 3. In Fig. 2, the relative standard deviation, σ_{rel}, for the sheet resistance, R_0, the Hall mobility, μ_H, and the Hall sheet carrier density, N_{HS} are plotted as a function of the width, w, of the test pad, for a pad length, L=7s and a distance to the boundary, y_0=0.4s. As can be seen, the shape of the curves for the three different parameters is quite similar, although off-set from each other, with the sheet resistance assuming the lowest values and the Hall sheet carrier density the highest. The standard deviation remains low until the width of the test pad has been shrunk to around w=3.5s, at which point the geometry starts to affect the precision. In other words, it is possible, based on our simulations, to measure on test pads down to a size of 7s × 3.5s without compromising the precision on the measurement significantly.

In Fig. 3, the same three parameters are plotted for the "limit" rectangular test pad size of $7s \times 3.5s$, as a function of probe-pin distance to the parallel boundary. Below y_0=0.4s, the relative standard deviation stays below 3 % for the worst case (N_{HS}), 2 % for μ_H and less than 1 % for R_0 which is acceptable for monitoring purposes. The precision can be improved on all parameters by moving the probe closer to the edge, e.g. y_0=0.2s. Moving the probe closer to the edge than 0.2s, may prove too difficult in practice and further away than y_0=0.4s will severely affect the precision and is therefore not recommended.

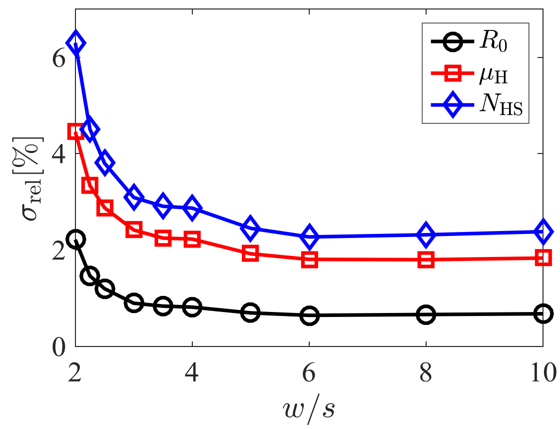

FIGURE 2. Relative standard deviation for R_0, μ_H and N_{HS} vs. width, w, of the test pad in question. The probe is placed at y_0 = 0.4s and the length, L, of the test pad is 7s. The relative standard deviation is seen to increase below w=3.5s.

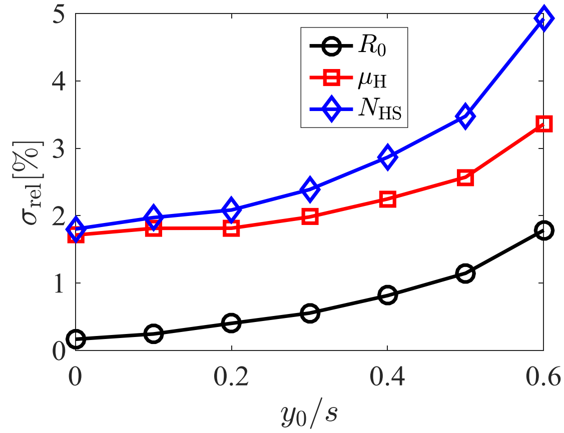

FIGURE 3. Relative standard deviation for R_0, μ_H and N_{HS} vs. distance to the edge, y_0, for w = 3.5s and L=7s. The probe should not be placed further from the edge than y_0 = 0.4s, which is the standard today, since a larger distance will lead to lower precision. Higher precision can be achieved by moving the probe pins closer to the boundary.

CONCLUSION

From this study it can be concluded that single engage micro Hall effect measurements can be performed with a micro 7 point-probe on rectangular pads down to a size of $7s \times 3.5s$ almost as accurately as on larger pads. The study also shows that if the sample parameters need to be determined more accurately, the relative standard deviation can be decreased by placing the probe close to the insulating boundary.

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KEYWORDS

Four-point probe, Hall effect, sheet resistance, electrical characterization.