On Wafer Characterisation of the Analog Anisotropic Magnetoresistance Sensor

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***Abstract* - This article presents the solution for a fast evaluation tool of an analog integrated Anisotropic Magnetoresistance Sensor (AMR) on a silicon wafer. It was necessary to evaluate a selected prototype development phase of a custom analog AMR sensor. This approach significantly shortened the development time as no dicing and packaging was required. We will also use this solution later for a final volume production wafer sorting. The biggest challenge was to quickly generate and release an accurate, sufficiently strong magnetic field that is as parallel as possible to the wafer surface. Such a field is needed to measure the peak values of the sine and cosine output signals of the analog AMR sensor.**

Keywords - analog AMR sensor; wafer sort; AMR sensitivity.

I. INTRODUCTION

Magnetoresistance (MR) is the tendency of selected material to change its electrical resistance value when an external magnetic field is present. Several effects are known [1], such as Anisotropic Magnetoresistance (AMR), Giant Magnetoresistance (GMR), Tunnel Magnetoresistance (TMR), Colossal Magnetoresistance (CMR) and Extraordinary Magnetoresistance (EMR). In contrast to isotropic MR materials, anisotropic MR materials [2] have a different resistance depending on the material's orientation in a magnetic field.

We can purchase several inexpensive MR and AMR sensors available on the market today. They are produced by manufacturers like Sensitec GmbH, STMicroelectronics, Honeywell, iC-Haus and many others. They are intended for measuring electric current, for the electronic compass, for the acquisition of linear position, speed or angle in technical equipment and similar [3]. The MR sensors are known for their reliability, accuracy, low cost and extreme resistance to environmental influences [4][5].

In our case, a local company has developed its version of the analog AMR sensor based on their specific needs. Our task was to produce this application-specific sensor. It was also necessary to quickly verify such analog AMR sensor components on silicon wafers to facilitate this task. Although there is a lot of literature about different AMR sensors, we could not find any good literature about the test implementation (including a sensitivity measurement) of an analog AMR sensor on a wafer. Therefore, we describe our solution to this problem in this article.

The ideal analog, variable resistance AMR sensor output, which corresponds to the changing magnetic field of the magnetic tape, shows Figure 1, and Figure 2 shows the equivalent circuit of the AMR sensor. It consists of two Wheatstone bridges. The first has four equal resistors R1, R2, R3 and R4 and the second also has four equal resistors R5, R6, R7 and R8. They are made of a thin tantalum layer. The upper Wheatstone bridge covers one half of the magnetic field period, and the lower Wheatstone bridge covers a second half of the magnetic field period.

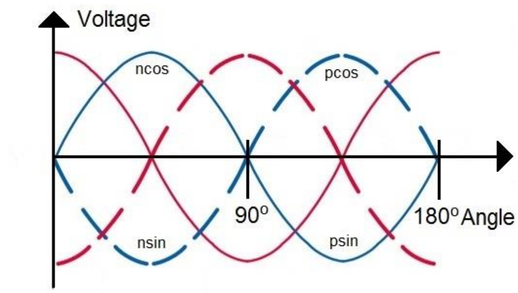

Figure 1. Ideal analog AMR sensor output of ncos, pcos, nsin and psin signals.

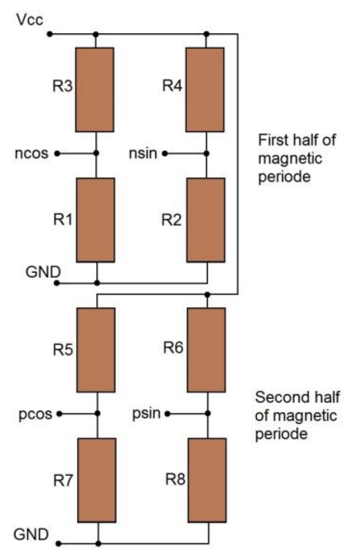

Figure 2. AMR equivalent circuit.

The problem here was to generate an appropriate magnetic field while probing a Device Under Test (DUT) on the wafer prober. The requirement was to immediately obtain a peak value of the sensor sensitivity of the sine and cosine curve. The direction of the magnetic field must be as

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parallel as possible to the silicon wafer's surface. An additional limiting factor is a small opening in the test probe card (Figure 3) and the fragile contact probes' proximity. The magnet's free space in the middle of the probe-card with six test probes is magnified for better presentation.

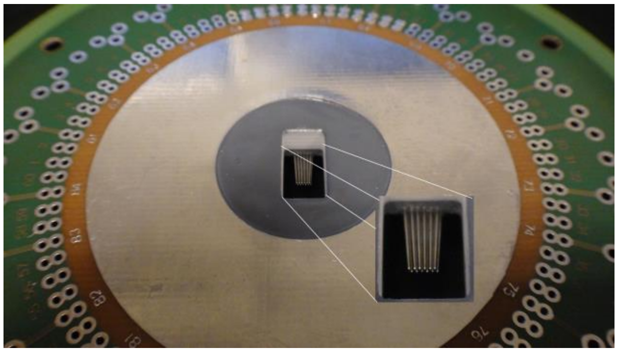

Figure 3. AMR test probe card with twelve test probes in the middle. We need two probes per pad for four-wire measurement.

The test sample's sensitivity level should be as close as possible to the sensitivity level measured near the magnetic tape (Figure 4). The device's most relevant parameters are the signal amplitudes at terminals "ncos-nsin" and "pcos-psin". In addition to the sensitivity, we must also measure each resistance in a double Wheatstone bridge.

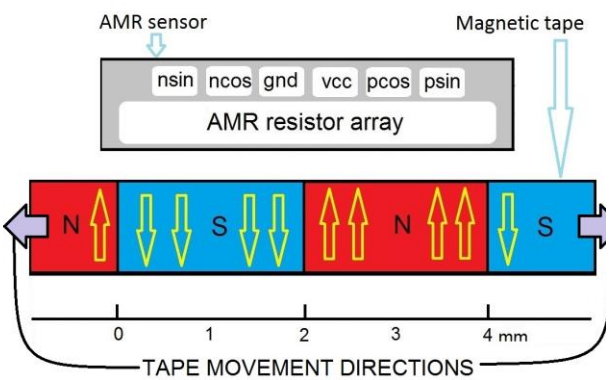

Figure 4. AMR sensor with six pads and resistor array near the magnetic tape.

Other important parameters are the offset voltages at "ncos-nsin" and "pcos-psin" when no magnetic field is present. The current consumption is also a part of the characterization, which is monitored during development and production. A small hysteresis of the outputs we consider, at this stage, is guaranteed "by design" itself. At the moment, the hysteresis can only be measured by using a magnetic tape when we change the direction of tape travel according to the AMR sensor.

Section 2 describes a precise mechanism that allows a magnetic field generation near a silicon wafer's surface and in proximity to the test needles without damaging them. Section 3 describes some AMR sensitivity results, and section 4 describes some ideas for further improvement of the AMR sensor on the silicon wafer characterization procedure.

II. MATERIALS AND METHODS

To develop the analog AMR sensor's optimal resistor geometry and layer structure, it was necessary to cut a silicon wafer, place the sensor device into a test package, and then measure all the sensor's critical parameters, including the sensitivity. These measurements were performed with specially designed hardware and an alternating magnetized magnetic tape (Figure 4) perpendicular to the AMR sensor. We are talking about a magnetic field with a typical strength of 30mT. Figure 4 shows the top view of the AMR sensor with pads and resistor array. The distance from the 1mm thick tape to the sensor is adjustable from 0.5 to 1.5mm, and the dimension of the sensor is about 1 x 4mm.

To avoid this time-consuming step, we decided to use a small neodymium magnet to create a permanent magnetic field and a special structure to transfer this field close to the silicon wafer's surface. The magnetic field direction should be as parallel as possible to the surface of the silicon wafer. This structure was custom made from a soft ferromagnetic material [6]. After performing some simulations and experimenting with different shapes and materials, we selected a final form shown in Figure 5.

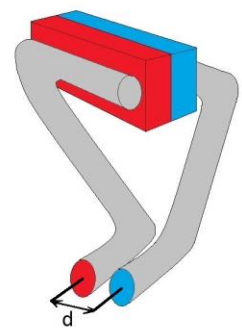

Figure 5. Structure from neodymium magnet and ferromagnetic material. Distance "d" is 2mm

During wafer sorting, it is essential to perform some measurements with and without a magnetic field. It was necessary to develop a precision mechanism (Figure 6) with an actuator.

This mechanism allows us to position the magnetic field with a small joystick within a few micrometer range. The hinge is made of a thin steel sheet. The entire mechanism is screwed onto the test probe card and later adjusted under a microscope.

III. RESULTS

The repeatability of measurements in the magnetic field is in the range of 1.6% of the measured value. By accurately adjusting the magnetic field near the DUT, we can measure the maximum amplitude of the sine and cosine signals. The measured values are almost identical to the values measured later on packaged parts near the magnetic tape. We have the best matching score at the one mm sensor-tape gap. Figure 7 shows a graph of the differences between two sequentially repeated sensitivity measurements for 100 devices. The typical peak amplitude of the sensitivity amplitude is 50 to 60 millivolts and the standard deviation of the difference in repeated measurements is 0.9 mV. Blue colored values in Figure 7 present differences between cosine amplitude and red values present differences between sine amplitude.

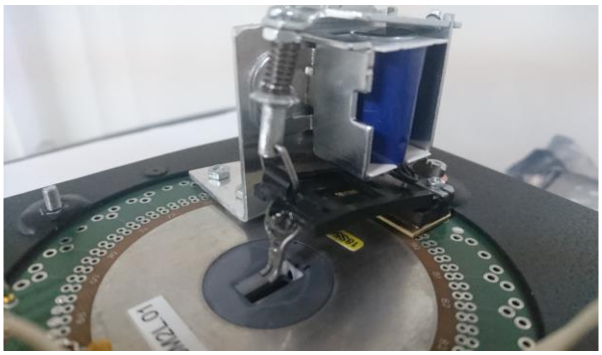

Figure 6. Probe card with fine adjustable magnetic field actuator.

During wafer sort, the magnetic field generation and settling time is approximately twenty-five milliseconds, and the total test time per DUT is about 40 milliseconds. The magnetic field is reset to zero as the wafer prober moves the probes to the next device. At this point, the magnetic field actuator increases the distance between the wafer surface and the magnet structure in Figure 4. The gap rises from a few micrometers to about ten millimeters. No magnetic influence on the AMR sensor can then be detected.

Some additional parameters for the optimal exploitation of one device are presented in Table 1. There are some characteristics concerning three different distances of the test AMR sensor sample from the magnetic tape. The typical space in the final application is 0.5 mm.

The sensor's resistance does not change significantly with the magnetic field distance, as shown in the table's second line. The sensitivity at the magnetic field change is also within the required range, and we can also expect some offset values.

IV. CONCLUSION

With this method we have tested several thousand analog AMR sensors so far. This approach significantly shortened the development time for a customer-specific, analog AMR sensor. Further development in this area is in replacing the mechanical actuator and permanent magnet with a microfine coil with permalloy or soft magnetic composite materials [6] core for even faster magnetic field generation. We have already carried out some experiments in this direction but had problems with the field strength and the limited space near the test probes.

TABLE 1. AMR SENSOR TEST SAMPLE RESULTS.

	measurement1	measurement2	measurement3	
Tape Distance	0.10	0.50	1.00	mm
Resistance	0.9316	0.9362	0.9418	kOhm
Amplitude sin	66.74	65.91	60.96	mV
Amplitude cos	66.69	65.83	60.85	mV
Offset sin	3.80	4.15	3.97	±mv
Offset cos	4.92	4.94	4.86	±mV
Hysteresis	0.00	0.9	4.24	µm

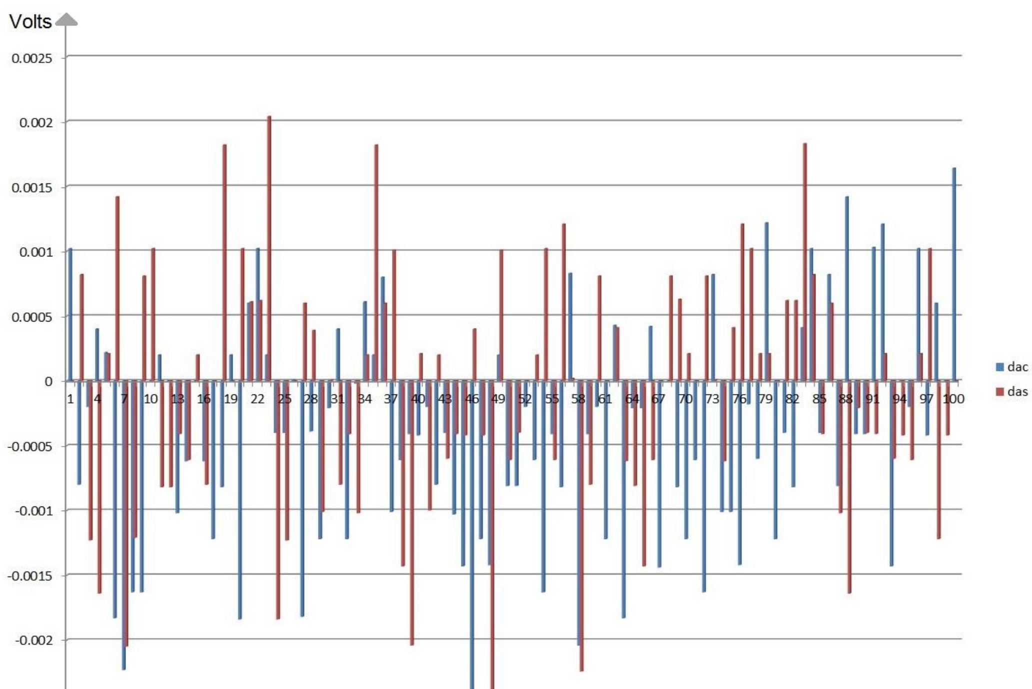

Figure 7. AMR sensitivity repeating measurement difference graph in volts for 100 devices with standard deviation of 0.9mV.

The data in Table 1 were obtained from the described test procedure on the wafer. Measurements were averaged with a 16-bit analog to digital conversion and with hi gain. Accuracy and repeatability were also verified with a calibrated, professional voltmeter.

The hysteresis cannot be measured with the described method. It can only be determined by moving a sensor or magnetic field in both directions (Figure 4). However, our solution to this problem is currently patent pending and will be published shortly.

Additionally, we also see the upgrade of the overall process in the improvement of the AMR sensor geometry and its performance [7][8].

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