Direct Monitoring of Battery SOC Utilizing GMI-IDT Magnetic Sensor

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***Summary*—A novel micromagnetic sensor is designed and optimized for direct and non-invasive measurement of the State of Charge (SOC) (via magnetic properties) of Li-ion batteries. Potential applications include (Hybrid) Electric Vehicles (EV) and other electric battery-driven systems. A single surface acoustic wave (SAW) interdigital transducer (IDT) is used as the sensing platform shunt loaded with amorphous microwires based on Giant Magnetoimpedance (GMI) effect. The sensor design has been optimized to achieve maximum sensitivity, linearity, and repeatability required for battery cell measurement, and for the first time, the response of the proposed sensor in monitoring of actual EV cell properties is presented. The results are a promising first step towards a sensor device for direct battery SOC measurement and open an opportunity in gaining information about the remaining charge capacity and battery performance.**

Keywords—Magnetic sensor; GMI effect; GMI wire; single SAW IDT; IDT transduction process; battery internal state

I. INTRODUCTION

Efficient battery management systems (BMS) in rechargeable battery-based systems require precise measurements of battery parameters including SOC to monitor for safety, reliability, charge capacity and battery health. Present SOC measurement techniques mostly involve long-term measurement of current, open circuit voltage (OCV), and temperature. These techniques are indirect and require knowledge of the history of the battery to prevent excessive inaccuracy. Therefore, a novel way of monitoring the internal state of the battery via magnetic sensing is introduced here by measuring the magnetic properties of the battery electrodes. As has been shown previously for Li-ion batteries, the magnetic susceptibility of the electrode material varies during battery charging and discharging conditions. As a result, battery SOC can be probed via an appropriately designed magnetic sensor system.

II. METHODS AND RESULTS

Previously, a detailed model of the GMI-IDT sensor was described along with the sensitivity equation [1]. In the present work, the sensor design is further optimized by compensating the combined capacitive effect of the IDT and other circuit elements with an appropriately selected series matching inductor, and the optimized design is tested in monitoring the magnetic properties of EV-type Li-ion battery cells. Experimental results confirm that the addition of the matching element doubles the sensitivity of the sensor for a frequency of operation of 104 MHz as shown in Fig. 1. To establish linearity and frequency dependence of sensitivity, the sensor is calibrated using an electromagnet in the range of ~58 to 81 μT as shown in Fig. 2. This calibration ensures that the sensor can detect even minute changes in the magnetic field while operated at or near its peak sensitivity. Note that the expected change in magnetic susceptibility of the battery cell during charging and discharging is very small, thus the proposed sensor must have a high sensitivity in the low magnetic field (~μT) range with good linearity. Next, the geometry of the magnetic sensor and location of the reference magnetic field with respect to the battery must be optimized to maximize the change in magnetic field the sensor will measure for a given change in magnetic susceptibility during battery charging and discharging conditions. The schematic diagram of the experimental setup is given in Fig. 3. The measurement results for charging of a Li-ion pouch cell are given in Fig. 4, showing the change in magnetic field that was calculated from the sensor response using Fig. 1. To monitor the magnetic properties of the cell during charging, battery voltage and magnetic sensor output were recorded for 10 loops, each consisting of 15 min of charging followed by 40 min of rest. The measured change in magnetic field agrees with the theoretical value expected for a single pouch cell [2].

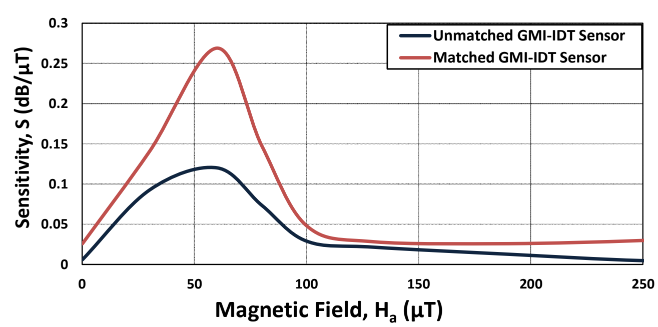

Fig. 1. Measured sensitivities of GMI-IDT sensors for unmatched and matched sensor designs operated at 104 MHz frequency.

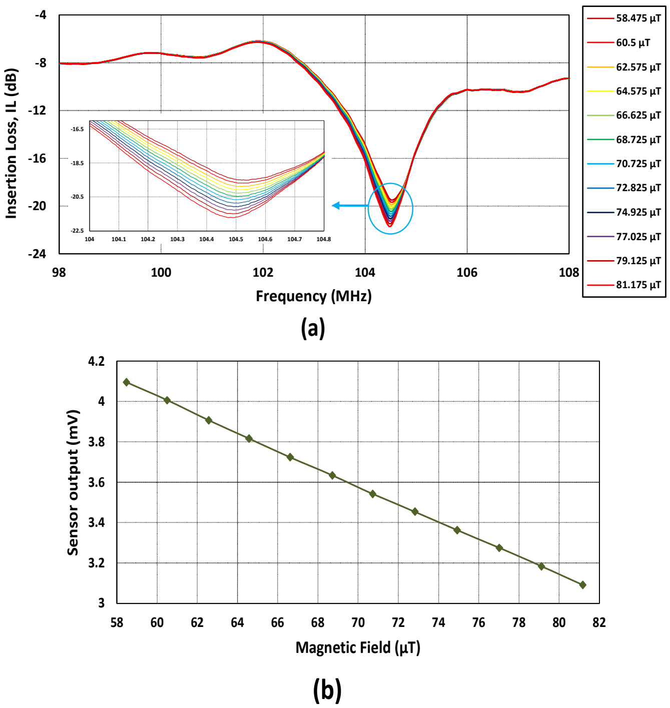

Fig. 2. The GMI-IDT sensor response is calibrated using an electromagnet (maximum pull force of 18 kg). (a) The highest sensitivity is observed at the SAW center frequency (see inset). (b) Observed linearity of sensor response (in the probed magnetic field range) at 104.41 MHz.

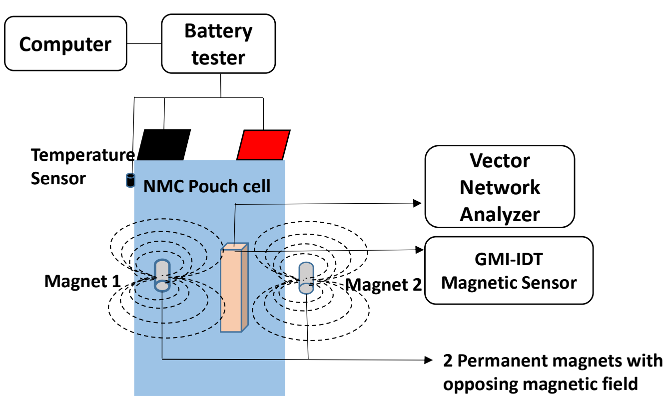

Fig. 3. Schematic diagram of the experimental setup. Two permanent magnets (with 2.8 kg of pull force each) were used for reference field. Magnet 1 is attached to the cell and thus is sensitive to changes in cell susceptibility; magnet 2 is used for partial compensation of the magnetic field of magnet 1 so the sensor can be operated in its most sensitive range (~60 µT) considered as the baseline magnetic field.

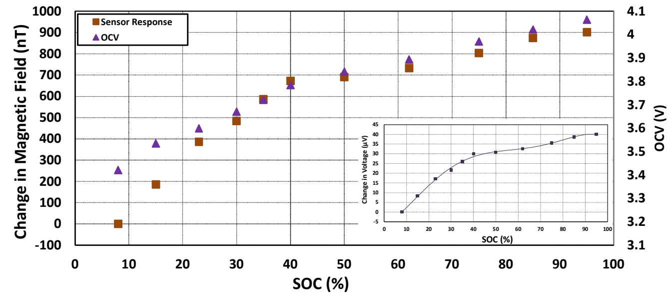

Fig. 4. Experimental results of Li-ion pouch cell (charging) measurement with GMI-IDT sensor. The measurement consists of 10 loops, each including a charge step of 15 mins followed by a rest step of 40 mins. The data points were collected in between the charge steps hence at the rest step to ensure the battery is in equilibrium state. The overall change in magnetic field is ~0.9 µT for a 90% change in SOC. The inset shows the corresponding sensor response. The observed nonlinear sensor response could be related to the nonlinear electrode chemistry of the pouch cell.

REFERENCES

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