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Miniaturized Cantilever Device with a Broad Measurement Area to Determine Two Orthogonal Magnetic Flux Density Components

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Introduction: Measurement of magnetic flux densities is an important task in many research areas and is commonly associated with Hall sensors. Unfortunately, Hall sensors suffer from offset phenomena. To get rid of this intrinsic offset, the mechanical excitation of a micro machined structure by the Lorentz force can be used as qualified transducer mechanism. Besides that, such actuators have a fundamental linear dependence between force and electrical current, as well as between force and magnetic flux density. By adapting the electrical current, the sensor offers a high sensitivity and a large dynamic range enabling measurement of both strong and weak magnetic fields.

Sensor principle: The sensor consists of a micro machined U-shaped Si-cantilever, which is fixed at the endpoints of the U. This device bears a thin current flowed lead on its top, which, when it is placed into a magnetic field, gets deflected by the Lorentz force acting on the elastic structure. This deviation is, in case of small deflections compared to the length of the cantilever, directly proportional to the product of flux density and electrical current. With known current strength, which is prescribed by a control circuit, the magnetic field density can be determined. To gain high sensitivity and to eliminate the influence of mechanically prestressed cantilevers, the use of a resonant mechanism is advisable. Therefore, the cantilever is excited by an alternating current with a frequency equal to an eigenfrequency of the elastic structure. This is an efficient way because of the high quality factors of Si-structures, where the damping is mainly determined by the surrounding air. The U-shaped cantilever exhibits complex vibration modes. The linearity of this system allows the simultaneous excitation of different modes, whereas the individual modes do not influence each other. The symmetrical and the antisymmetrical mode are excited by orthogonal flux densities. In the symmetric mode the cantilever arms are parallel to the magnetic field and only the U-base is loaded. In the antisymmetric mode the U-base is parallel to the field and two oppositely directed forces load the arms of the structure. To excite two modes simultaneously, the electrical current on the cantilever consists of two AC current components (10 mA) with frequencies according to the resonant frequencies (5.8 kHz and 16 kHz) of the first symmetrical and first antisymmetrical mode. The oscillations are contact less detected by an optical readout using a commercial available reflective sensor. The Au-lead on top of the cantilever acts as a mirror. The output signal of the reflective sensor is amplified using a high-speed precision operational amplifier and analyzed by two lock-in amplifiers using the respective frequency for reference input. The signal amplitudes of the lock-in amplifiers are proportional to the magnetic flux densities in z- and y-direction, respectively. The phase information of the lock-in amplifiers is used to determine the polarity of the magnetic field.

Fabrication: To manufacture the device, metal lines are evaporated onto backside passivated $<100>$ Si-wafers and patterned with an image reversal photo-resist and lift-off technique. The resulting lead consists of a 0.5 μm thick Au-layer of 60 μm width. After backside lithography, the backside nitride is patterned and the wafer is wet-etched anisotropically, leaving a thin Si-membrane. Next, the shape of the cantilever is etched from the top side using a dry reactive ion etching process. The finished cantilever has a length of 1500 μm and an overall width of 1000 μm. The cross-sectional dimensions are given by a width of 100 μm and a thickness of 10 μm.

Results: To demonstrate the system's high measurement range from μT up to more than 1 T, the flux densities of the earth's magnetic field and of a NeFeB-magnet are measured. Compared to commonly used Hall Effect sensors for earth magnetic field measurement, the offset of our cantilever based measurement principle is only given by the electrical cross talk. The measurement range can be adapted conveniently by changing the excitation current. For small magnetic field measurement, the excitation current is thermally limited by the dissipated power to about 100 mA, whereas for high magnetic fields (small currents) no principal limit is expected.