Simulated and Measured Characteristic of a Micromachined Cantilever Sensor

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The miniaturized sensor is designed for measuring high magnetic flux densities. A micro machined U-shaped cantilever, which is moved by the Lorentz force, acts as deflecting mirror in an optical readout system. The ratio of the intensity of the light reflected by the front side of the cantilever to the intensity of the incident light is analyzed. Simulated and measured signals generated by the oscillating cantilever and their dependence on the exciting force are shown.

Introduction

High magnetic fields in the range up to 50 T are usually produced with cylinder coils placed in liquid nitrogen [1]. During the magnetic pulse, the Joule heat raises the temperature from 77 K up to room temperature. These ambient conditions make the measurement of high magnetic fields a highly sophisticated task. The presented sensor should be used to improve the control of the thyristor rectifier of the power source to get constant magnetic fields during the pulse. Due to the quasi-static conditions, induction coils are not applicable because they mainly detect the higher harmonics and have zero sensitivity at DC-field.

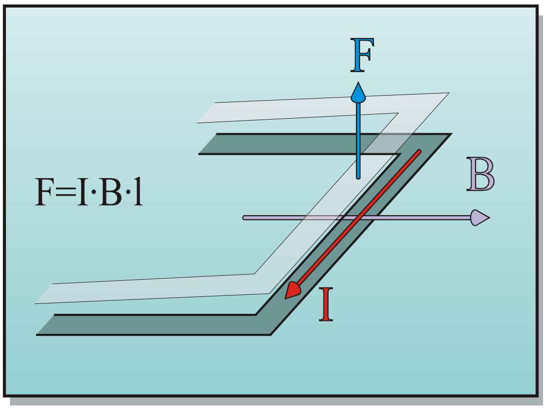
Sensor

For measuring the magnetic flux density, the bending of a U-shaped Si-cantilever is used. This deformation is caused by the Lorentz force (Fig. 1, left) on an electrical lead which is placed on top of the cantilever structure (Fig. 1, right). Neglecting the base of the U-shaped cantilever and the influence of the lead on the mechanical behavior the deflection d is given by

$$d = F_L \frac{2l^3}{Ebh^3} \qquad (1),$$

where h, b, l and E denote the thickness, width, length and Young's modulus of the cantilever and F_L the Lorentz force, respectively. The bending in Eq. (1) is a linear measure of the force assuming the length of the cantilever is much larger than its deflection.

Because the Lorentz force is proportional to the magnetic flux density and to the electrical current, the same deflection is produced if the field is reduced and the current is increased by the same factor. This enables the sensor development and calibration without high field equipment.



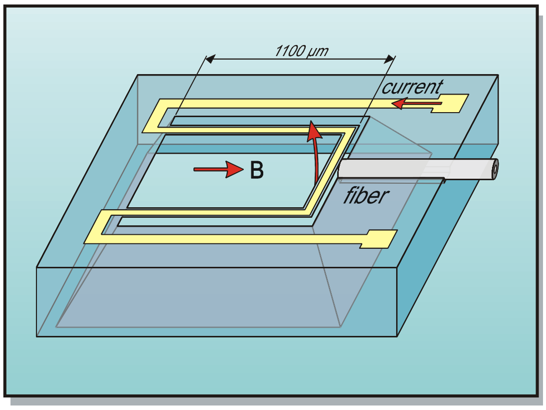


Fig. 1: Transducer principle (left) and sensor setup (right).

Many methods in detecting the position of a cantilever use capacitive sensing [2], [3] or strain gauges situated at the clamped ends of the suspension arms [4]. These methods work well when the electronic amplifier can be placed in the close vicinity of the moving part. Due to the low temperatures and high field change rates in the target application, the electronic parts have to be distant from the sensor.

Optical Readout [5]

Thus, the deflection of the cantilever is detected optically by measuring the light that is reflected by the front side of the cantilever. The light (IR-LED) is emitted and captured by the same optical fiber, which makes the mechanical setup as simple as possible.

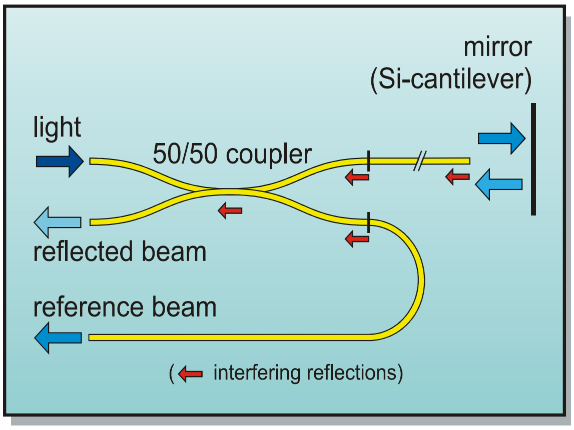


Fig. 2: Schematic drawing of the optical readout of the cantilever position.

To obtain ratiometric results, the light was split up into a reference beam and a measurement beam using an optical coupler (Fig. 2). The measurement beam is guided by a multi mode fiber (Corning 50/125) to the front side of the cantilever. The amount of reflected light depends on the cantilever position according to the section of the fiber that is opposite to the cantilever.

Initially, an infrared laser was used as light source, which offers intensity in the mW-range. However, due to the small number of modes propagating in the multimode fiber and to the reflected light back to the laser, the stability of the signal was low and the measurement setup became extremely sensitive to mechanical vibrations of the fiber.

For the simulation, a simple model was applied, assuming that only near field phenomena are of relevance. The reflecting front side of the cantilever, which acts as a moving mirror, was replaced by a moving slit in a non-transparent screen. Its width is equal to the cantilever thickness. The fiber is virtually split up into an emitting fiber and a capturing fiber that is situated at the mirror image of the emitting one.

To get a measured characteristic of the optical readout a piece of silicon was attached to the membrane of a loudspeaker and actuated at a frequency of 500 Hz. With a micromanipulator, the position of the fiber in respect to the cantilever has been varied. The measured characteristic (Fig. 3 left, circles) is nearly perfectly fitted by the simulated one. The differences indicate that the effective cantilever thickness is a little bit higher than in the simulation. The assumed Gaussian light distribution seems to be a suitable approximation (Fig. 3 left, solid line).

Sensor Characteristic

If we assume an ideal alignment of the fiber with respect to the cantilever, the cantilever faces the center of the fiber. We get a constant amount of the light for the still standing cantilever. For small oscillation amplitudes, the output signal is almost sinusoidal (Fig. 3 right). If the amplitude increases further, the cantilever gets out of sight of the fiber for a section of the oscillation period. The signal shows two peaks. The higher the amplitude becomes the more the peaks width shrinks.

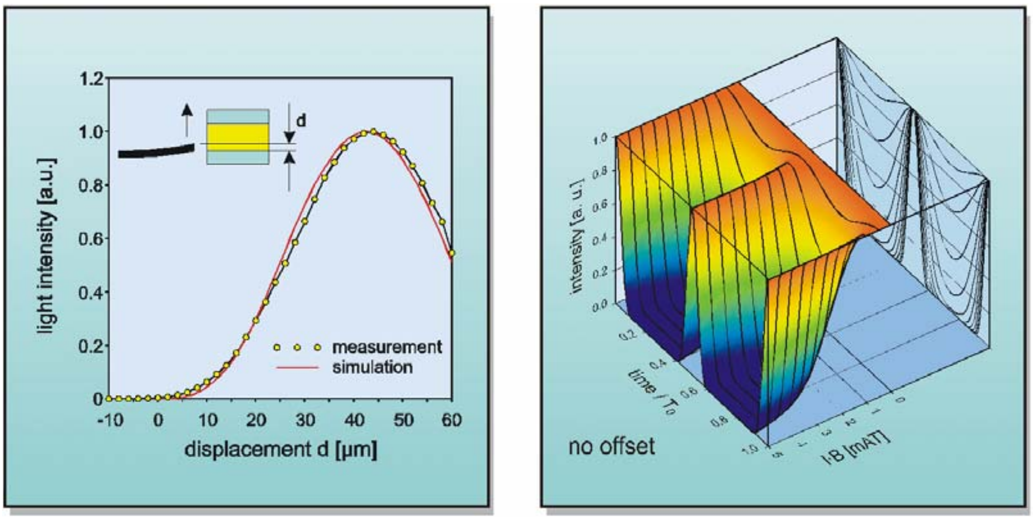


Fig. 3: left: Numerically modeled and measured characteristic of the optical readout. Both curves were scaled to unity.
right: Simulated Signals generated by an oscillating cantilever assuming ideal alignment.

For a real device, the center of the fiber cannot be aligned exactly with the zero position of the cantilever. The stress in the multilayer structure is bending the cantilever and the depth of the groove for guiding the optical fiber cannot be properly adjusted. The resulting offset changes the characteristic of the optical readout (Fig. 4 left). The varying peak height is a consequence of the limited resolution of the readout simulation. This effect increases the more the peaks width decreases.

The sensor signals (Fig. 4 right) were measured at 4800 Hz, which is 200 Hz below the resonant frequency. This frequency was chosen to get a suitable current range for the sensor characterization. The agreement with the measurements confirms the model underlying the simulation. The differences occur from system properties that are not taken into consideration yet. The decreasing maximum amplitude of the measured signals with increasing I·B (corresponds to oscillation amplitude) is caused by the electronic amplifier which has a small bandwidth to reduce the noise.

With the available current load of the lead which is about 100 mA we expect a measurement range from of 40 mT to >40 T.

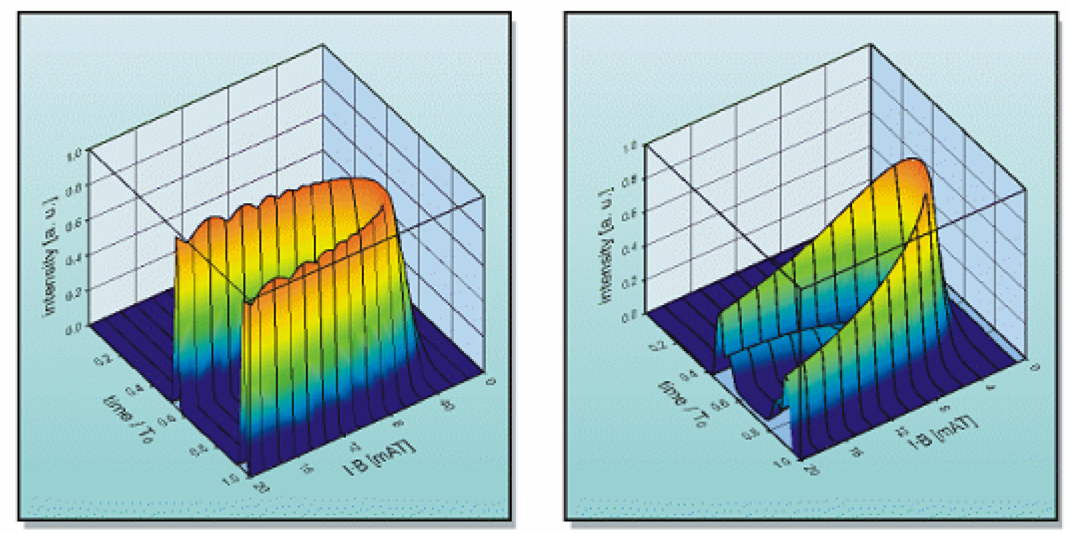


Fig. 4: left: Simulated signals generated by an oscillating cantilever assuming an offset of 40 μ.
right: Measured intensity signals depending on the amplitude ($\propto I \cdot B$)

Acknowledgements

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