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"Improved Directional Drilling Technology for the Bakken Formation"

Quarterly Report
December 31, 2009

Contract No.:	G017-37
Effective Date of Contract:	June 8, 2009
Contract Expiration Date:	June 30, 2010
Reporting Period:	October 1, 2009 to December 31, 2009

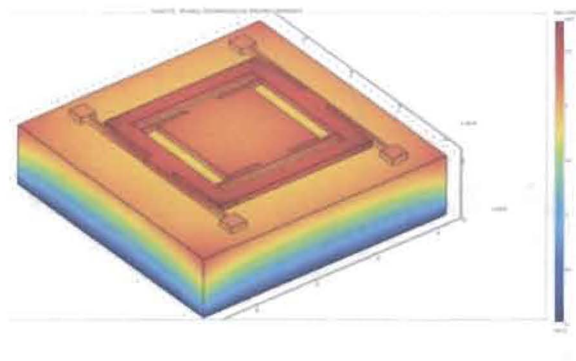
Non-Confidential Section

The intent of this project is to increase the efficiency of horizontal drilling in the Bakken Formation by including the use of miniature gyroscopes in the drilling assemblage. The result of the project will be a prototype miniature MEMS gyroscope demonstrated at temperatures typical in the drilling environment. In particular, high-temperature shock-resistant MEMS gyroscopes enable the directional sensor to be positioned next to the drill bit, resulting in more accurate navigation, and reduction in drilling cost and time.

During the past quarter, the high temperature gyroscope designs were completed. Figure 1 shows computer simulation results that indicate that the gyro sensor design will not buckle under the harsh thermal conditions and should operate successfully.

An initial MEMS fabrication run was also performed to produce MEMS test structures within design specifications for linewidth and sidewall quality. Figure 2 shows an example of a fabricated test structure.

An initial circuit design has been developed for driving the gyroscopes and sensing changes in capacitance in the range of picofarads.



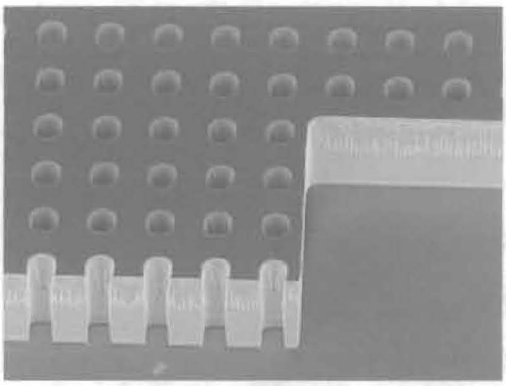


Figure 1. COMSOL simulation graph confirm gyroscope stability at 200 C.	**Figure 2. Fabricated test structures confirm MEMS process accuracy for the design specifications.**

Non-Confidential Background Information

It is imperative to bring reliable, domestic hydrocarbon reserves on-stream to help the United States reduce dependency on foreign oil. Hence, the Bakken Formation, with estimated reserves at 200-400 billion barrels of oil, is a critical national asset that needs to be developed to its maximum capacity. At present, only 1%-3% of Bakken reserves are anticipated to be recovered due in part to limitations with existing oilfield technology, including limitations in the accuracy of existing directional drilling technologies. The current technology, magnetometers, cannot be significantly improved since the errors are introduced by external sources.

Gyroscopes are inertial sensors that measure rate of rotation (in °/sec or °/hr), without reference to external coordinates. MEMS vibratory gyroscopes are based on Coriolis acceleration, which arises in a rotating frame of reference and is proportional to the rate of rotation. The gyroscope is forced to vibrate (typically using inter-digitated comb drives) in the sense axis at its characteristic resonant frequency. When subjected to angular rotation, the vibrating mass feels Coriolis acceleration in the direction orthogonal to the drive direction and axis of rotation. This motion in the sense direction is directly proportional to the rate of rotation and is typically measured using capacitive sensing.

The Coriolis force can be computed using the equation below, with the mass of the gyro (*m*), rate of rotation (Ω_z), drive displacement (*Xo*), and drive frequency (ω_x). The sense motion of a single proof mass gyroscope is at the same frequency as the drive motion. Hence, by demodulating the sense signal at the drive resonant frequency one can obtain the angular rate of rotation.

$$F_y = 2m\Omega_z X_o \omega_x \cos(\omega_x t)$$

Non-Confidential Project Results

Coventor Architect software was used to design the gyroscope and verify the analytical calculations. Architect is a system level simulator that solves for the solutions to a system using lumped mass modeling. The system (including the MEMS device, and the supporting electronics) is drawn in a similar fashion to an electrical circuit, using lumped element representation for each of the components.

The resulting final design is a 1mm x 1mm SOI device, with a thickness of 20µm, and a smallest feature size of 2µm (limited by process uncertainty). A single mask fabrication is possible, further reducing errors due to misalignment; additional masks may be required to pattern metal for bond pads and contact pads. A multi-fold sensitivity increase is achieved as compared to the initial gyroscope design.

Non-Confidential Upcoming Tasks

Upcoming work for the next period will include a final check of the device layouts and an initial fabrication loop of the actual gyroscope designs. The circuit design will be finalized, and the building of the test setup will start. An additional task will be the design and assembly of a test chamber for demonstrating gyroscope operation under high temperatures.