



## “Improved Directional Drilling Technology for the Bakken Formation”

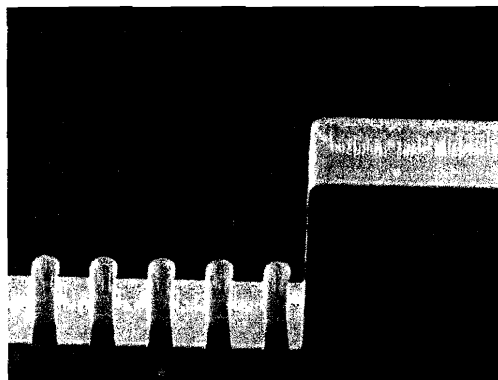
Quarterly Report  
March 31, 2010

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Effective Date of Contract: June 8, 2009  
Contract Expiration Date: June 30, 2010  
Reporting Period: January 1, 2010 to March 31, 2010

### *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, additional testing and process development of gyroscopes from the initial MEMS fabrication run were completed. This work includes testing the electrical properties and the mounting and packaging of the sensor (Figure 1). Data gathered from testing has aided in adjusting the design for the upcoming fabrication run. The control circuit design was completed and is currently being fabricated. A vacuum test chamber for the gyroscope has been built which will be used to create a test setting typical of a drilling environment.



**Figure 1. 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 ( $\Omega_z$ ), drive displacement ( $X_o$ ), and drive frequency ( $\omega_x$ ). 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***

The resulting final design is a 1mm x 1mm SOI device, with a thickness of 20 $\mu$ m, and a smallest feature size of 2 $\mu$ m (limited by process uncertainty). Testing has verified that the sensor can be fabricated using a single mask, further reducing errors due to misalignment. 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 fabricating the new gyroscope design and packaging it together with the control circuit. These will then be installed in a test chamber to test its ability to measure angular rotation in a high temperature environment.