Magnetically-Modulated Ionization in a MEMS-Based Three-Electrode Sensor for Vector Detection of Weak Power-Frequency Fields

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The interaction between low-frequency magnetic fields and weakly ionized plasmas is underexplored in applied magnetism. While Hall-effect [1], magneto-resistive [2], fluxgate [3], and induction-based sensors [4] rely on solid-state phenomena, they face sensitivity-size-frequency trade-offs in sub-mT, 50/60 Hz regimes. We introduce a micro-electromechanical system (MEMS) sensor in which an external magnetic field B modulates a steady-state Townsend discharge. The device features a three-electrode structure with engineered silicon micro-column arrays that create localized field enhancements ($E > 3 \times 10^6$ V/m), initiating field emission, described by the Fowler-Nordheim equation:

$J_e = \frac{A\beta^2 E^2}{\phi} \exp\left(-\frac{B\phi^{3/2}}{\beta E}\right)$,

where J_e is the emission current density, ϕ the work function, and B a material constant. Under applied B-field, orthogonal or parallel to the drift field E, alters electron trajectories via the Lorentz force ($F_L = e(v \times B)$), thereby increasing electron-neutral collision frequencies and enhancing ionization yields. This magnetically-amplified ion current provides a direct, linear measure of the AC field magnitude and direction, and thus the ion current I_c collected at the collector electrode.

Experimentally, the sensor shows a sensitivity of 0.152 nA/μT for fields parallel to the electrodes, and 0.08 nA/μT for perpendicular fields. Using a BP neural network processing, directional field detection and zero-drift compensation are achieved, improving linearity to 1.60%.

This work demonstrates a new, miniaturized magnetometry approach based on magnetically modulated gas discharge, relevant for environmental and industrial low-frequency magnetic field monitoring.

Keywords: Magnetic field sensor, Gas ionization, MEMS, Silicon microstructure, Fowler-Nordheim emission, Lorentz force

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