# Magnetic Vortex Oscillators Driven by Spin-Polarized out-of-Plane dc Current

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## 1. Introduction

Spin-polarized dc-current driven self-sustained magnetic vortex oscillators (MVOs) have been experimentally demonstrated using a nanoscale spin valve structure[1]. Since then, the MVOs have begun to attract considerable attention. These MVOs have several advantages over the spin-transfer-torque(STT) driven nano-oscillators based on the precessional motion of uniform magnetizations in magnetic nanoelements. In recent studies, several groups have reported the dynamic excitation of vortex oscillations in different types of nanostructures by using out-of-plane dc currents[2-8]. Although these previous studies have proposed and demonstrated a new concept of nano-oscillators based on vortex translation mode excited in magnetic nanodots, quantitative understandings of the underlying physics, of not only this phenomenon but an associated new phenomena, has yet been explored.

In this presentation, we report on the quantitative interpretations and the results of vortex oscillations in a free standing soft magnetic nanodot driven by spin-polarized out-of-plane dc current. We conducted analytical calculations and numerical simulations, considering both the STT effect of the spin-polarized current acting directly on vortex nonuniform magnetization structure and a comparable Oersted field (OH) effect accompanying the current flow.

## 2. Analytical calculation and simulation result

To obtain key parameters for the control of eigenfrequency and the amplitude of the radius of an orbital motion of a vortex core (VC) in a circular-shaped nanodot of different vortex states determined by vortex chirality $c$ and polarization $p$, we analytically calculated a moving VC position vector, $\boldsymbol{X}(t) = [X(t), Y(t)]$ in the dot $(x\text{-}y)$ plane, where $X$ and $Y$ are the $x$ and $y$- components of $\boldsymbol{X}(t)$. In this derivation, we utilized the linearized Thiele's equation of motion by employing the STT term. In response to a spin-polarized out-of-plane dc current, it was revealed that $\boldsymbol{X}(t) = [X(t), Y(t)]$ is expressed as $\boldsymbol{X}(t) = \mathbf{X}_0 \exp(\omega_I t)\exp(-i\omega_R t)$ with the true eigenfrequency of VC gyrotropic motions $\omega_R$, the changing rate of the orbital amplitude $\omega_I$, and the initial VC displacement $\mathbf{X}_0$. The analytically calculated terms $\omega_R$ and $\omega_I$ are found to be controllable with only the external driving parameters of the current density $j_0$ and its direction, for a given vortex state characterized by p and c, and direction of the perpendicular magnetization of the polarizer in a given dot geometry.

Furthermore, we numerically calculated both the critical current density, jcri, for persistent vortex oscillations with the initially displaced VC orbital radius kept and their eigenfrequency $\omega_R^{cri}$ (at j0 = jcri) versus the dot dimensions, thickness $L$ and radius $R$. These constructed phase diagrams offer how to design dot dimensions and to select a proper material for controlling persistent vortex oscillations and their eigenfrequencies. The jcri values show the dramatic variation with $L$ for a given $R$, whereas $j_{cri}$ varies slowly with $R$ for a constant value of $L$. It is surprising that the value of $j_{cri}$ is as low as the order of 104 A/cm$^2$ in the region of $L < 3$ nm, and the eigenfrequency is tunable in a broad range from 10 MHz to 2 GHz.

## 3. Conclusion

This work provides a stepping stone for its practical applications to persistent oscillators tunable in a broad frequency range, without applying additional large in-plane and perpendicular magnetic fields. This work is supported by Creative Research Initiatives (ReC-SDSW) of MEST/KOSEF.

## 4. References

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