Orthogonal shape/intrinsic anisotropy toggle mode magnetoresistance random access memory

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Motorola patented MRAM----toggle model

Synthetic AF memory cell

Sequential application of $H_w$ and $H_d$

Corresponding magnetization configurations

Large operating field margin, only for high operating field!

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Conventional MRAM vs. toggle-mode MRAM

Toggle MRAM’s advantage:
Large operation field margin can be obtained.

Toggle MRAM’s disadvantage:
At lower operating field, may not have margin advantages over conventional MRAM

To obtain the lower operating field becomes the key issue for toggle mode MRAM.
Energy expression

\[ E = E_u + E_{sh} + E_{msc} + E_J + E_Z \]

\[ \Delta E = 2 [K_u + (1 - r) K_{sh}] V = 2K^*V > \Delta E_c \]

\[ H_k^* = 2K^*M_s \]

Stable at \( H_{appl} = 0 \)

\( K_u > 0 \)

\( K_u < 0 \)
Necessary Condition for Memory Element

\[ K^* = K_u + (1-r) K_{sh} > E_c / V \]

\[ K_t = K_u + K_{sh} > r K_{sh} + E_c / V \]

For \( K_{sh} < 0 \),

\( K_t \) can be either positive or negative!
Energy Mapping at Zero Applied Field

\[ \theta_2 \quad \theta_1 \]

Low energy \quad High energy

\[ h_{k,t} = H_{k,t}/H_{k,*} \]

\[ h_{k,t} = 1 \]

\[ h_{k,t} = 0 \]

\[ h_{k,t} = -1 \]
Magnetization configurations – constant-angle contour

\[ \xi = (\theta_1 + \theta_2)/2 \]
\[ \eta = (\theta_2 - \theta_1)/2 \]

\[ h_{k,t} = 0 \]
\[ h_{k,t} = 1 \]
\[ h_{k,t} = -1 \]
Critical field curves and field trajectory for toggle switching

Switch happens:

\[
h_{flop} < h_w + h_d < h_{x,s}
\]

Optimal \( h_w \) or \( h_d \):

\[
h_{w, opt} = \frac{(h_{flop} + h_{x,s})}{(2\sqrt{2})}
\]

New switch trajectory

\[
h_{x,s} = h_{couple} - h_{k,t}
\]

\[
h_{flop} = \sqrt{h_{couple} + h_{k,t}}
\]

(for \( h_{k,t} > 0 \))

\[
h_{flop} = \frac{(h_{couple} - h_{k,t})}{\sqrt{h_{couple} + h_{k,t}}}
\]

(for \( h_{k,t} < 0 \))
Magnetization configurations around the astroids constant-\(\xi\) contours

Hysteretic phase

Nonhysteretic phase

Worledge APL 84 2847 (2004)

\(h_{k,t} = 1\)

\(h_{k,t} = -1\)
Critical Fields for Switching and Margin

Critical fields ($h_{\text{flop}}$, $h_{x,s}$, and $h_{c,\text{margin}}$)

Coupling field, $h_{\text{couple}}$

$\begin{align*}
\text{Critical fields} &
\quad \begin{cases} 
    h_{k,t} & \text{for } h_{k,t} \\
    -1 & \text{for } -1 \\
    0 & \text{for } 0 \\
    1 & \text{for } 1 
\end{cases} \\
\text{Critical fields} &
\end{align*}$
The lowest operating field is available for $h_{k,t} = 0!$
Margin is the green filled area.
Conclusion

- Magnetization response to in-plane applied fields has been studied, using Stoner-Wohlfarth model, on the bilayer systems of synthetic antiferromagnet having an anisotropy configuration in which the induced intrinsic uniaxial anisotropy is set either parallel or orthogonal to the shape anisotropy.

- Lowest operating field and high relative operating field margin are attained by compensating the shape anisotropy by the intrinsic anisotropy, which can be realized by setting both anisotropies orthogonal to each other.

- Optimal operating fields increase with the increase of the absolute value of the total anisotropy constant.

- The tolerance of total anisotropy constant in the positive direction is greater than that the negative direction if zero total anisotropy is chosen to be optimal.
Reference


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