MgO-based magnetic tunnel junctions (MTJs) have been exploited toward an ultrahigh tunnel magnetoresistance (TMR) through the large interfacial PMA between MgO and transition-metal (TM) alloys. The PMA of 1.4 MJ/m³ at the interfaces between MgO and Fe has been achieved [1]. As an understanding of PMA induced at the interface between the ferromagnetic and linear polarized beams. The XAS line shapes show clear metallic states without convergence to positive, which is related to the sign of integral of XMLD intensities in Fig. 1(b) that the integral of XMLD intensities to be positive; that is, unoccupied 3d orbitals are slightly elongated to the out-of-plane direction. We note that XMLD is defined as \( \mathbf{M} \perp \mathbf{E} \) – \( \mathbf{M} \parallel \mathbf{E} \), where \( \mathbf{M} \) and \( \mathbf{E} \) is the magnetization and the electric filed vector of incident synchrotron, respectively, resulting that the positive XMLD means preferential coupling with the out-of-plane unoccupied orbitals. However, since the denominator in the sum rule is two orders of magnitude larger than that of the numerator, the absolute value of \( Q_{zz} \) is estimated to be less than 0.01, which is interpreted as less than 1% unoccupied orbital polarization of Fe 3d states. On the other hand, electron occupancies are slightly shrinking through the relation \( Q_{xx} + Q_{yy} + Q_{zz} = 0 \). The XMCD with the angular dependence also deduces the quite small magnetic dipole term \( m_{\uparrow} \) using the spin sum rule. These results are consistent with the fact that the contribution of \( m_{\uparrow} \) is two orders of magnitude smaller than that of \( m_{\downarrow} \) (1.73 \( \mu_B \)) [4]. We note that the notation of \( Q_{zz} \) is independent of spin-orbit coupling of Fe, suggesting that the origin of \( Q_{zz} \) is derived from the interfacial asymmetry and strain.

\[ Q_{zz}(\mathbf{Q}) = \frac{\int \mathbf{E} \cdot (\mathbf{M} \times \mathbf{E}) d\mathbf{Q}}{\int \mathbf{E} \cdot \mathbf{M} d\mathbf{Q}} - \frac{\int \mathbf{E} \cdot \mathbf{E} d\mathbf{Q}}{\int \mathbf{E} \cdot \mathbf{E} d\mathbf{Q}} \]

The XMLD sum rule suggests that the integrals of XMLD line shapes are proportional to \( Q_{zz} \). We confirmed in Fig. 1(b) that the integral of XMLD intensities converges to positive, which is related to the sign of \( Q_{zz} \) in dichroism to be positive; that is, unoccupied 3d orbitals are slightly elongated to the out-of-plane direction. We note that XMLD is defined as \( (M \perp E) - (M \parallel E) \), where \( M \) and \( E \) is the magnetization and the electric filed vector of incident synchrotron, respectively, resulting that the positive XMLD means preferential coupling with the out-of-plane unoccupied orbitals. However, since the denominator in the sum rule is two orders of magnitude larger than that of the numerator, the absolute value of \( Q_{zz} \) is estimated to be less than 0.01, which is interpreted as less than 1% unoccupied orbital polarization of Fe 3d states. On the other hand, electron occupancies are slightly shrinking through the relation \( Q_{xx} + Q_{yy} + Q_{zz} = 0 \). The XMCD with the angular dependence also deduces the quite small magnetic dipole term \( m_{\uparrow} \) using the spin sum rule. These results are consistent with the fact that the contribution of \( m_{\uparrow} \) is two orders of magnitude smaller than that of \( m_{\downarrow} \) (1.73 \( \mu_B \)) [4]. We note that the notation of \( Q_{zz} \) is independent of spin-orbit coupling of Fe, suggesting that the origin of \( Q_{zz} \) is derived from the interfacial asymmetry and strain.

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References

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