Unconventional bias dependence of tunnel magnetoresistance induced by the Coulomb blockade effect

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Generally, tunnel magnetoresistance (TMR) monotonically decreases with increasing the bias voltage, which limits the bias voltage range for operation of magnetic tunnel junctions (MTJs). Recently, to overcome this limitation, an unconventional bias dependence of the TMR, in which the TMR increases with increasing the bias voltage, has been reported in a quasimagnetic tunnel junction (QMTJ) composed of CoO/ Co/ AlO_x/ EuS/ Al [1]. Also, enhanced TMR via a quantum size effect and resonant tunneling has been reported [2–5]. However, the abovementioned ways to modulate the bias dependence of TMR have their own restrictions; for example, the QMTJs need low temperature environment and the resonant tunneling effect requires well-controlled epitaxial heterostructures. Therefore, exploring ways to operate MTJs in a high bias voltage range, which do not depend on material systems, is important for applications to spintronics devices.

In this study, using double-barrier MTJs composed of Fe (8.0 nm)/ MgO (3.0 nm)/ Fe (8.0 nm)/ γ-Al_2O_3 (2.2 nm) grown on Nb-doped $SrTiO_3$ (001) substrates [Fig. 1(a)] [6], we demonstrate unconventional bias dependences of TMR, in which the TMR ratio increases with increasing the bias voltage even at 300 K [Fig. 1(b)]. This behavior is induced by a giant zero-bias resistance peak of the γ-Al_2O_3 layer, which likely originates from the Coulomb blockade (CB) effect via Fe impurities that are diffused from the Fe layer to the γ-Al_2O_3 layer (Fig. 2). We show that the voltage drop of the MgO barrier is negligibly small in a low bias voltage range, and as a result, TMR can be observed even in the high bias voltage range. We have experimentally observed the TMR ratio of 23% even at −4 V at 3.5 K, which is a very high value for this large bias voltage range. Our results offer a novel way to operate MTJs in an arbitrary bias voltage range by using the CB effect [7].

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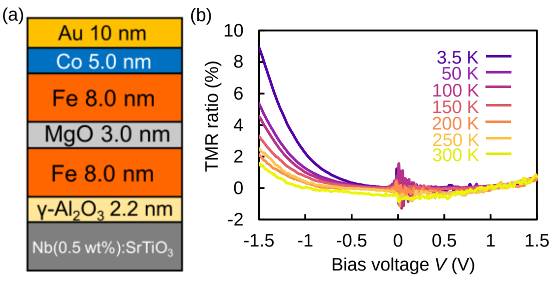

Fig. 1. (a) Sample structure (b) TMR versus bias voltage V at temperatures ranging from 3.5 K to 300 K.

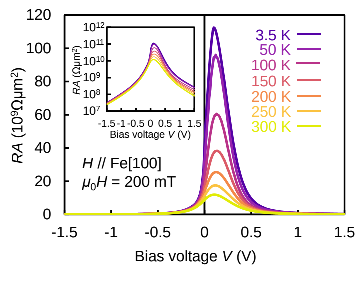

Fig. 2. Resistance-area product RA versus bias voltage V of the device in Fig. 1(b) at temperatures ranging from 3.5 to 300 K. The inset shows the same curves, in which the vertical axis is logarithmic.

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