Supplementary Information to "Realisation of all 16 Boolean logic functions in a single magnetoresistance memory cell"

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Fig. S1 Schematic fabrication process of the Fe/MgO/Fe/Co PSV-MTJ. (a) Pristine Fe/MgO/Fe/Co multilayers on MgO substrate and covered with Au protecting layer. (b–d) Schematic device structures after each intermediate step. (e) Final PSV-MTJ with bond pads to top and bottom electrodes. S and numbers in the parentheses denote substrate and layer thickness values (unit, nm), respectively.

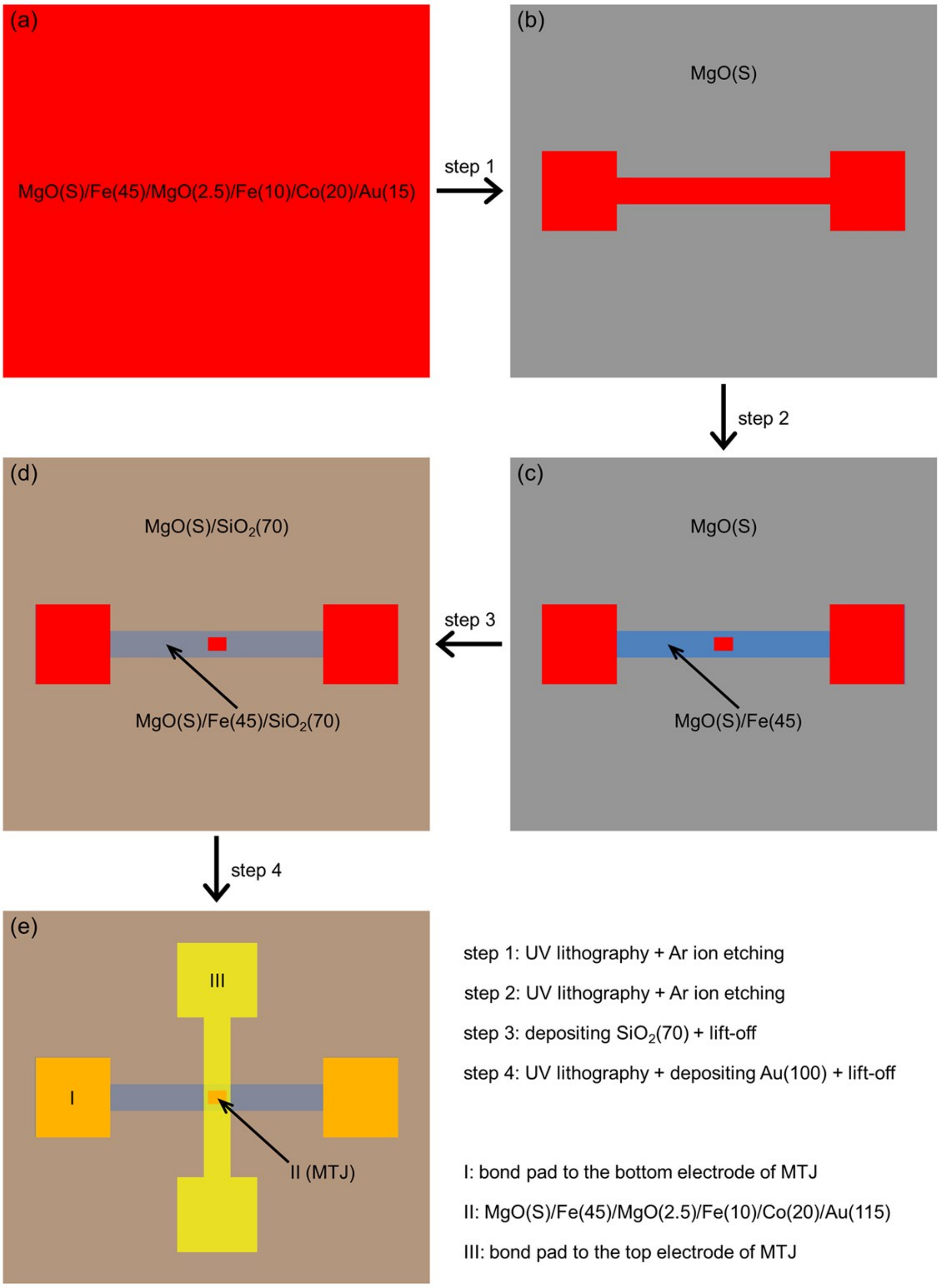

Fig. S2 (a) Optical image of the Fe/MgO/Fe/Co PSV-MTJs. Five PSV-MTJs share a common bottom electrode. I and II denote the bond pads to bottom and top electrodes of PSV-MTJs, respectively. Measurement configuration and external magnetic field direction are clearly shown. (b) Scanning electron microscope image of the junction region. Despite a little deviation in shape caused by UV lithography, the real junction area is close to the designed one of $5 \times 10\ \mu m^2$.

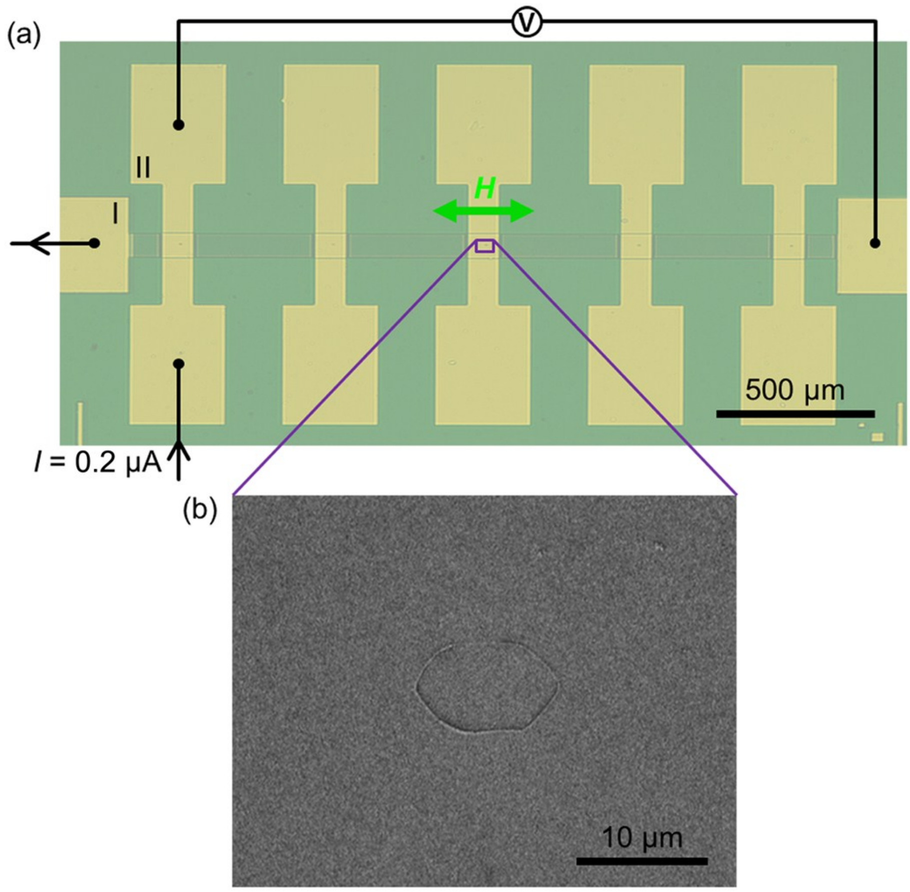

Fig. S3 The stability of the Fe/MgO/Fe/Co PSV-MTJ. The red and blue curves were obtained before and after the logic operations in Fig. 3a, respectively. The little difference between these two curves indicates good stability of the Fe/MgO/Fe/Co PSV-MTJ.

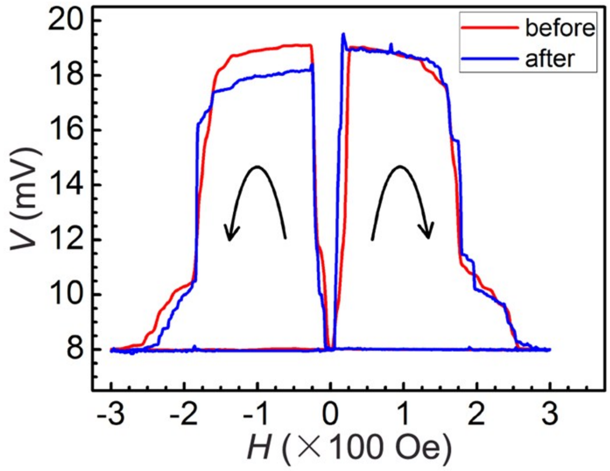

Fig. S4 Schematic fabrication process of the LSMO-based AMR unit. (a) Pristine LSMO/SCO bilayer on STO substrate. (b) Schematic device structure after UV lithography and wet etching. (e) Final LSMO-based AMR unit with bond pads. S and numbers in the parentheses denote substrate and layer thickness values (unit, nm), respectively.

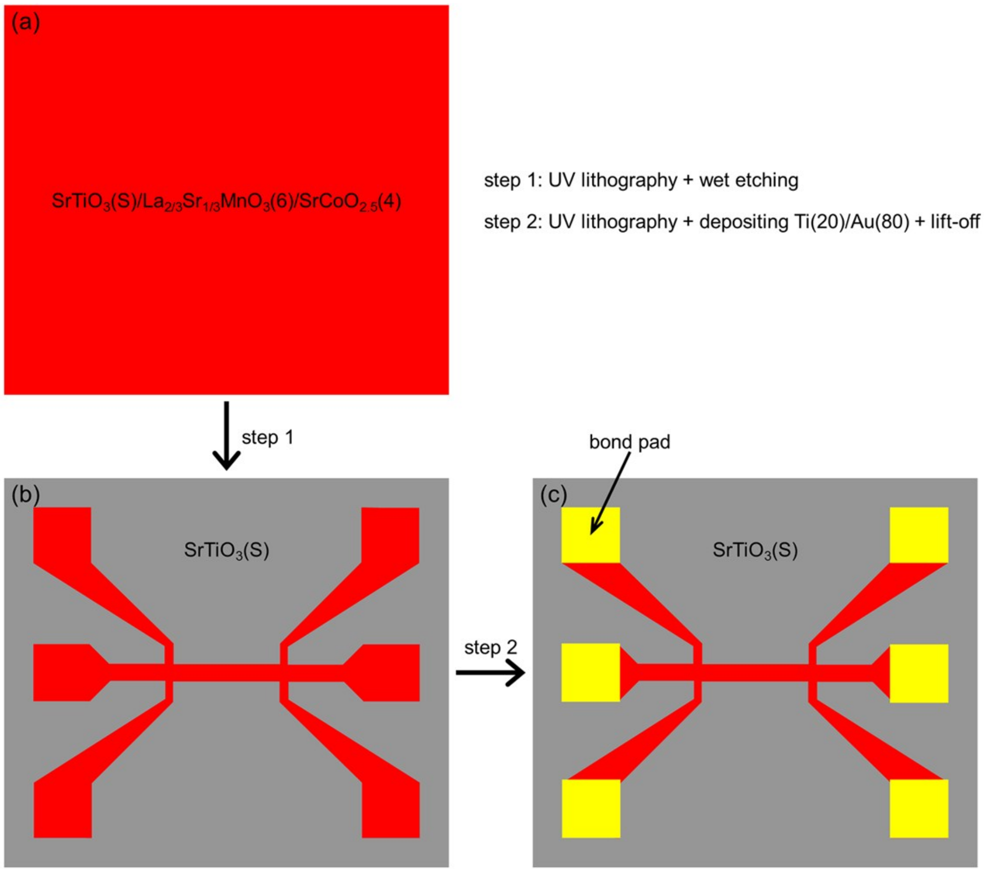

Fig. S5 (a) Optical image of the LSMO-based AMR unit. I and II denote bond pads and gate electrodes, respectively. It is noted that gate electrodes are useless in the current work. Measurement configuration and external magnetic field direction are clearly shown. It can be easily seen that the effective Hall bar channel is 400 μm in length and 100 μm in width.

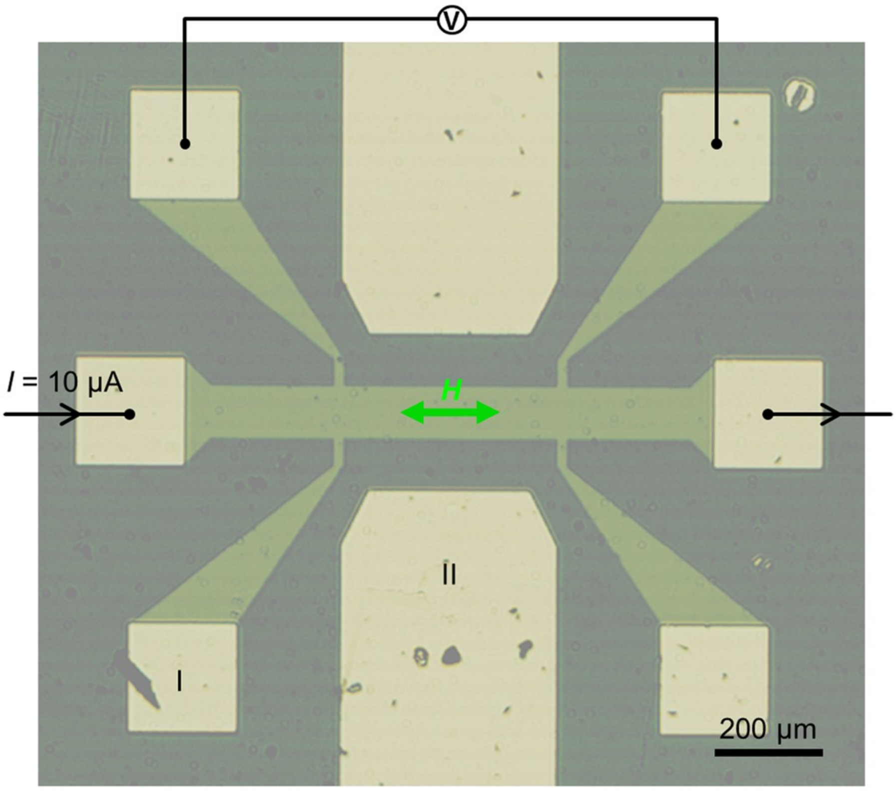

Table S1 The truth table of other 14 Boolean logic functions and corresponding experimental results in Fig. 3. '¬*p*' in this table represents the NOT *p* operation, i.e., ¬*p* (*p* = 0) = 1 and ¬*p* (*p* = 1) = 0.

Logic operation	Input		Output	W1			W2			W3	Experimental result
	p	*q*		S_1	S_2	$S_1 - S_2$	S_1	S_2	$S_1 - S_2$	(S_1, S_2)	
True	0	0	1	0	1	–1	*p*	0	0	¬*p* = 1	(a3), (b3)
	1	0	1	0	1	–1	*p*	0	1	¬*p* = 0	(a2), (b2)
	0	1	1	0	1	–1	*p*	0	0	¬*p* = 1	(a3), (b3)
	1	1	1	0	1	–1	*p*	0	1	¬*p* = 0	(a2), (b2)
False	0	0	0	0	1	–1	*p*	0	0	*p* = 0	(a4), (b4)
	1	0	0	0	1	–1	*p*	0	1	*p* = 1	(a1), (b1)
	0	1	0	0	1	–1	*p*	0	0	*p* = 0	(a4), (b4)
	1	1	0	0	1	–1	*p*	0	1	*p* = 1	(a1), (b1)
p	0	0	0	0	1	–1	1	*p*	1	1	(a1), (b1)
	1	0	1	0	1	–1	1	*p*	0	1	(a3), (b3)
	0	1	0	0	1	–1	1	*p*	1	1	(a1), (b1)
	1	1	1	0	1	–1	1	*p*	0	1	(a3), (b3)
q	0	0	0	0	1	–1	1	*q*	1	1	(a1), (b1)
	1	0	0	0	1	–1	1	*q*	1	1	(a1), (b1)
	0	1	1	0	1	–1	1	*q*	0	1	(a3), (b3)
	1	1	1	0	1	–1	1	*q*	0	1	(a3), (b3)
NOT *p*	0	0	1	0	1	–1	1	*p*	1	0	(a2), (b2)
	1	0	0	0	1	–1	1	*p*	0	0	(a4), (b4)
	0	1	1	0	1	–1	1	*p*	1	0	(a2), (b2)
	1	1	0	0	1	–1	1	*p*	0	0	(a4), (b4)
NOT *q*	0	0	1	0	1	–1	1	*q*	1	0	(a2), (b2)
	1	0	1	0	1	–1	1	*q*	1	0	(a2), (b2)
	0	1	0	0	1	–1	1	*q*	0	0	(a4), (b4)
	1	1	0	0	1	–1	1	*q*	0	0	(a4), (b4)
p AND *q*	0	0	0	0	1	–1	*p*	*q*	0	*p* = 0	(a4), (b4)
	1	0	0	0	1	–1	*p*	*q*	1	*p* = 1	(a1), (b1)
	0	1	0	0	1	–1	*p*	*q*	–1	*p* = 0	(a6), (b6)
	1	1	1	0	1	–1	*p*	*q*	0	*p* = 1	(a3), (b3)
p OR *q*	0	0	0	0	1	–1	*q*	*p*	0	*p* = 0	(a4), (b4)
	1	0	1	0	1	–1	*q*	*p*	–1	*p* = 1	(a5), (b5)
	0	1	1	0	1	–1	*q*	*p*	1	*p* = 0	(a2), (b2)
	1	1	1	0	1	–1	*q*	*p*	0	*p* = 1	(a3), (b3)
p IMP *q*	0	0	1	0	1	–1	*p*	*q*	0	1	(a3), (b3)
	1	0	0	0	1	–1	*p*	*q*	1	1	(a1), (b1)
	0	1	1	0	1	–1	*p*	*q*	–1	1	(a5), (b5)
	1	1	1	0	1	–1	*p*	*q*	0	1	(a3), (b3)
p NIMP *q*	0	0	0	0	1	–1	*p*	*q*	0	0	(a4), (b4)
	1	0	1	0	1	–1	*p*	*q*	1	0	(a2), (b2)
	0	1	0	0	1	–1	*p*	*q*	–1	0	(a6), (b6)
	1	1	0	0	1	–1	*p*	*q*	0	0	(a4), (b4)
p RIMP *q*	0	0	1	0	1	–1	*q*	*p*	0	1	(a3), (b3)
	1	0	1	0	1	–1	*q*	*p*	–1	1	(a5), (b5)
	0	1	0	0	1	–1	*q*	*p*	1	1	(a1), (b1)
	1	1	1	0	1	–1	*q*	*p*	0	1	(a3), (b3)
p RNIMP *q*	0	0	0	0	1	–1	*q*	*p*	0	0	(a4), (b4)
	1	0	0	0	1	–1	*q*	*p*	–1	0	(a6), (b6)

	0	1	1	0	1	–1	*q*	*p*	1	0	(a2), (b2)
	1	1	0	0	1	–1	*q*	*p*	0	0	(a4), (b4)
p XOR *q*	0	0	0	0	1	–1	*q*	0	0	$p = 0$	(a4), (b4)
	1	0	1	0	1	–1	*q*	0	0	$p = 1$	(a3), (b3)
	0	1	1	0	1	–1	*q*	0	1	$p = 0$	(a2), (b2)
	1	1	0	0	1	–1	*q*	0	1	$p = 1$	(a1), (b1)
p XNOR *q*	0	0	1	0	1	–1	*q*	0	0	$\neg p = 1$	(a3), (b3)
	1	0	0	0	1	–1	*q*	0	0	$\neg p = 0$	(a4), (b4)
	0	1	0	0	1	–1	*q*	0	1	$\neg p = 1$	(a1), (b1)
	1	1	1	0	1	–1	*q*	0	1	$\neg p = 0$	(a2), (b2)