Magnetic Tunnel Junctions Based on Chiral Self-Assembled Monolayers

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The chirality-induced spin polarization (CISS) effect has been described first by R. Naaman and D. Waldeck in 1999 [1]: tunneling of electrons through a chiral tunnel barrier results in a strongly spin-polarized electrical current. Since its discovery, the CISS effect has found many potential applications [2], e.g., in chromatography (enantiomer separation), energy conversion (water electrolysis), display technology (OLED) and spintronics. Basically, the physical effects of a chiral thin film on an electrical current correspond very much to that of a ferromagnetic or antiferromagnetic layer. Therefore, chiral thin films might serve as a simplified version of the rather complex stack used in state-of-the-art spintronics devices, such as STT or SOT MRAM [3] (Figure 1).

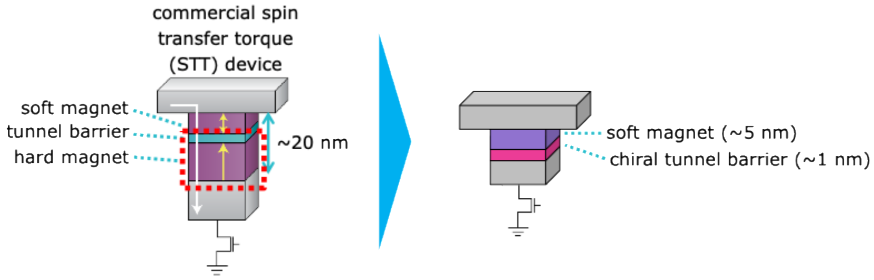

Figure 1. Design of a magnetic tunnel junction (MTJ) using a chiral self-assembled monolayer instead of a (anti)ferromagnetic pinned layer (PL) [3].

In principle, spintronic devices promise several advantages over other memory technologies: they are non-volatile, very fast switching (~1 ns), energy-efficient, and they have a small footprint on the chip (1T1MTJ) compared to, e.g., SRAM (6T). However, current commercial MRAM suffers from severe drawbacks such as a relatively low ON/OFF ratio (often <10) and a rather thick (up to 20 nm) pinned layer with a complex layer structure composed of materials which are difficult to process. This antiferromagnetic stack can be replaced by a much thinner (1 nm) chiral self-assembled monolayer (SAM).

The majority of functional SAMs described in the literature is based on thiols on gold substrates. This material combination is highly convenient to fabricate, but it has some serious drawbacks: thiol SAMs are quite sensitive to thermal and oxidative stress, and gold tends to diffuse in an uncontrollable manner. They are not even remotely suitable for a CMOS environment. Therefore, we are using 1,1'-binaphth-2-yl hydrogenphosphate (BNP) as a chiral building block, which is commercially available and readily forms robust covalent bonds to oxidic surfaces and is thus compatible to the most common materials used in semiconductor manufacturing processes (Figure 2). Phosphonate- and phosphate-anchored SAM are also robust enough for the deposition of a metallic top electrode, e.g., by sputtering [4].

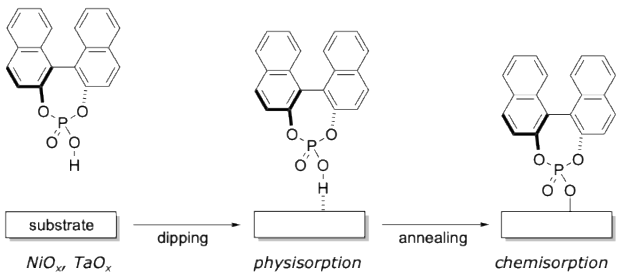

Figure 2. Covalent modification of oxidic substrates with *S*-BNP by a dipping process.

A first generation of chiral SAM-based MTJs using nickel substrates showed strong spin polarization (measured by cAFM or by eutectic gallium-indium alloy contacts) but needed a very high coercitive magnetic field (>0.5 T) to achieve the required out-of-plane magnetization. Therefore, we switched to Ta/CoFeB/MgO/Ta as a magnetic substrate. The BNP SAM was deposited onto the native Ta_2O_5 surface. For this device type a much lower coercitive field of 2-3 mT was sufficient to obtain complete out-of-plane magnetization. This device architecture is analogous to a commercial MRAM [5].

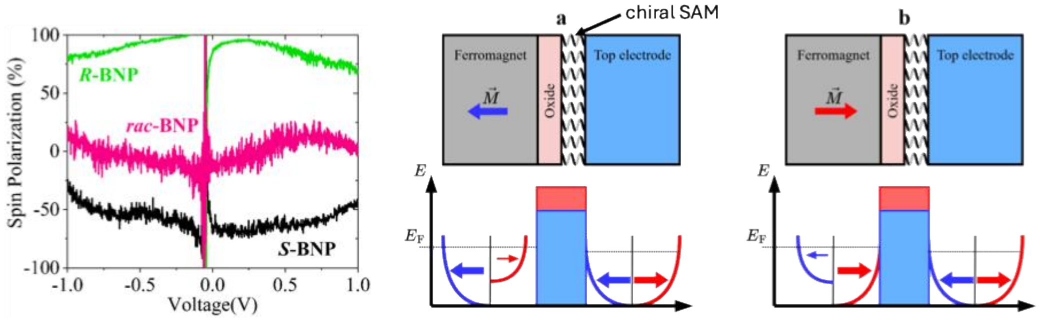

Figure 3. Voltage-dependent spin polarization of BNP on Ni (mcAFM) (*left*) and the tunneling model for MTJ adapted to the CISS effect (*right*).

large area compared to AFM!

Maximum spin polarizations for BNPs

	mcAFM/Ni (WIS)	mEGaIn/Ni (TUM)	cAFM/CoFeB, premagnetized (TUM)	mcAFM/CoFeB (TUM)	mEGaIn/CoFeB (TUM)
***R*-BNP**	~80%	~25%	~50%	~60%	~50%
***S*-BNP**	~70%	~15%	~40%	~70%	-

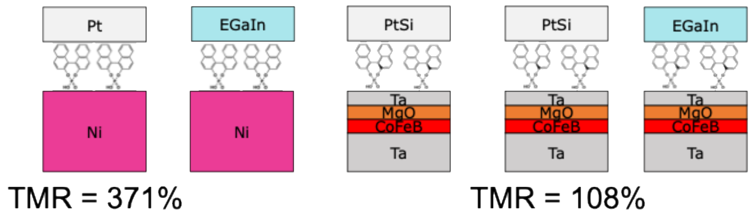

Table 1. Overview of spin polarizations and TMR values of BNP on Ni and CoFeB/MgO substrates measured by various methods. The world record is a TMR of 631% [6], and for a typical commercial MRAM 180% have been reported [5].

In summary, we demonstrated that with a very thin (1 nm) and chemically robust chiral BNP SAM on Ni substrates magnetic tunnel junctions (MTJs) can be obtained. A preliminary study on CoFeB/MgO substrates - requiring a much lower coercitive field - indicates similar results. The spin polarization effect has been observed with various different types of top contact - conductive AFM (~20 x 20 nm^2) vs. EGaIn (~100 x 100 μm^2) contact - with contact areas differing by at least 6 orders of magnitude.

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