Thema: All nitride TMR cells

Experiment set-up for Sample Structure MTJ

1- Thin-Film processing tecqnuques

A- Reactive Sputtering deposition

B- Lithographic processing

2- Magnetic and **Transport Characterization**

minor loop von von B-H looper magnetometry

TMR ratio $(R\mathrm{AP}-R\mathrm{P})/R\mathrm{P}$= %?

Resistance ?

Magneto optical Kerr effect measurements.

Temperatures from 1.5K to 500°C. Dc and AC-techniques ?

3-Structural and composition analysis:

Transmission Electron microscopy(TEM)
Scanning Electron microscopy(SEM)
X-ray diffraction and -reflection.

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Electron energy loss spectroscopy compositional mapping has confirmed that nitrogen is present in the barrier layer.

crystal structures and magnetic properties investigation

Titanium nitride (TiN) shows low resistivity at room temperature (27 µΩ cm)

ALN(crystalline)

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https://itp.tugraz.at/LV/ewald/TFKP/Literatur_Spintronics/

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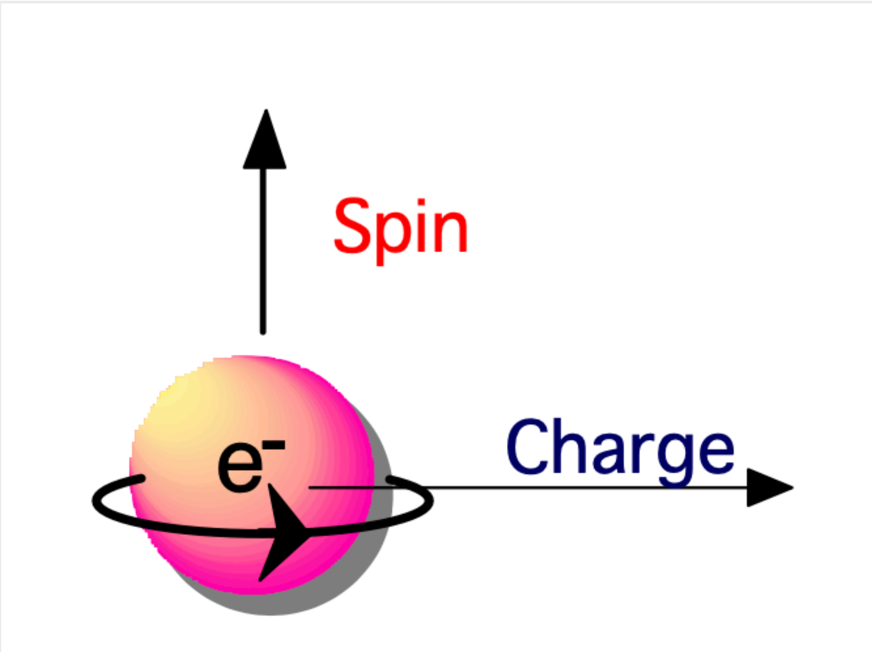
Kristall = Gitter * Basis

Reziprokes Gitter ist einfach die Fourier Transpiration .

the Néel temperature $T_N \approx 245$ K

In macroscopic spin transfer torque theory, the usual Landau-Lifshitz-Gilbert (LLG) equation of magnetization dynamics is augmented with spin transfer torque terms.



ferroelectrics

ferromagnetics
piezoelectrics
tailor-made poly- mers - a plethora
MEMs technology

The change in polarization produces a voltage change that can be used to make decisions,

Magnetization changes are exploited in technologies such as a recording medium.

In addition to these basic physical phenomena (charges) there may be other changes such as temperature changes, volume changes, etc., which can also be exploited for devices.

Devices such as diodes and field effect transistors that form the basis of modern semiconductor technology rely on being able to alter conductivity rapidly by an input signal.

In the more accurate quan- tum description, the electrons are described by waves with a certain wavelength and phase. In most cases, as electrons move in a solid, they suffer scattering, causing loss of phase coherence.

In ferroelectric materials the polarization can be altered by an external electric field.

The electric field-polarization relation shows a hysteresis curve, so that the direction of polarization at a zero applied field can be switched. Such an effect can be used for memory devices and is used widely for "smart cards."

of ferroelectric materials are used in modern technology and rapid advances in synthesis techniques promise more applications based on the ferroelectric effect.

Another physical effect based on polarization is the piezoelectric effect, where the polarization depends upon the strain applied to the sample. A potential signal can also produce strain in a piezoelectric material

A potential signal can also produce strain in a piezoelectric material. Materials like quartz and PZT are widely used for technologies based on the piezoelectric effect.

Technologies that use the piezoelectric effect include sensors/actuators (including developments in the micro- electro-mechanical systems or MEMs technology) and ultrasonics.

An interesting and important effect based on polarization is the pyroelectric effect in which a temperature change causes a polarization change in a material. This allows us to convert a thermal signal into a voltage signal (or vice versa). The pyroelectric effect is primarily used for thermal imaging, especially for night vision applications.

Magnetic effects arise in materials in which there is a net spin (intrinsic angular momen- tum associated with electrons) so that there is a magnetization in the system.

In some materials the magnetization can exist in the absence of any external magnetic field. Such materials are called ferromagnets. In other materials magnetization only arises in the presence of a magnetic field. Such materials are called paramagnetic or diamagnetic (depending upon whether the magnetization is parallel or opposite of the field).

-Master Ideas-Begriffen

X Ray werden an einem Fk gebeugt, wie Licht an optischen Gittern.

-Sputter deposition
-magnetron
-Physical vapor deposition
-Molecular-beam epitaxy
-**Tunnel magnetoresistance** (**TMR**) is a magnetoresistive effect that occurs in a **magnetic tunnel junction** (**MTJ**), which is a component consisting of two ferromagnets separated by a thin insulator. If the insulating layer is thin enough (typically a few nanometres), electrons can tunnel from one ferromagnet into the other. Since this process is forbidden in classical physics, the tunnel magnetoresistance is a strictly quantum mechanical phenomenon.

Magnetic tunnel junctions are manufactured in thin film technology. On an industrial scale the film deposition is done by magnetron sputter deposition; on a laboratory scale molecular beam epitaxy, pulsed laser deposition and electron beam physical vapor deposition are also utilized. The junctions are prepared by photolithography.

-Spin-transfer torque
Spin-transfer torque (**STT**) is an effect in which the orientation of a magnetic layer in a magnetic tunnel junction or spin valve can be modified using a spin-polarized current.
Charge carriers (such as electrons) have a property known as spin which is a small quantity of angular momentum intrinsic to the carrier. An electric current is generally unpolarized (consisting of 50% spin-up and 50% spin-down electrons); a spin polarized current is one with more electrons of either spin. By passing a current through a thick magnetic layer (usually called the "fixed layer"), one can produce a spin-polarized current. If this spin-polarized current is directed into a second, thinner magnetic layer (the "free layer"), the angular momentum can be transferred to this layer, changing its orientation.

-Spin-transfer torque memory

Spin-transfer torque can be used to flip the active elements in magnetic random-access memory. Spin-transfer torque magnetic random-access memory (STT-RAM or STT-MRAM)

-Magnesiumoxid
-amorphes Aluminiumoxid
-

-Hall effect

-Molecular-beam epitaxy (**MBE**) is an epitaxy method for thin-film deposition of single crystals. **MBE** is widely used in the manufacture of semiconductor .

-Nernst effect:In conducting ferromagnets, an anomalous Nernst effect—the generation of an electric voltage perpendicular to both the magnetization and an applied temperature gradient

-Scanning Auger Microscopy
Auger Electron Spectroscopy (AES) **provides quantitative elemental and chemical state information from surfaces of solid materials**. The average depth of analysis for an AES measurement is approximately 5 nm.

-Electron Beam Lithography (EBL) refers to a lithographic process that uses a focused beam of electrons to form the circuit patterns needed for material deposition on (or removal from) the wafer, in contrast with optical lithography which uses light for the same purpose.

- We need advanced nano fabrication.
- We start with a non-magnetic Substrate, and we deposit our magnetic material .then we soon our resist ,and we expose this we election writing beam .The resist ist developed as mask. Magnetic nanostructure

- Lithographiy writing
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Important for master thesis
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https://www.nature.com/articles/s41467-021-26915-3 (Spin-neutral currents for spintronics TMR)

https://www.nature.com/articles/nmat1256

Due to its high thermal conductivity, excellent dielectric properties and high chemical stability, aluminum nitride (AlN) is often used as electronics packages and heat sinks. In addition, AlN has recently been considered as an optoelectronic material due to its direct wide bandgap of 6.0 eV at room temperature and piezoelectricity. In an effort to develop energy saving devices, AlN-based deep-ultraviolet light-emitting devices[1,2,3,4,5,6,7,8,9,10,11,12,13], high electron mobility transistors[14,15], sensors[16], etc. have already been exploited.

https://www.nature.com/articles/srep17405

Transition metal nitrides

https://arxiv.org/pdf/2112.03457.pdf

https://pubs.rsc.org/en/content/articlelanding/2021/cs/d0cs00415d/unauth

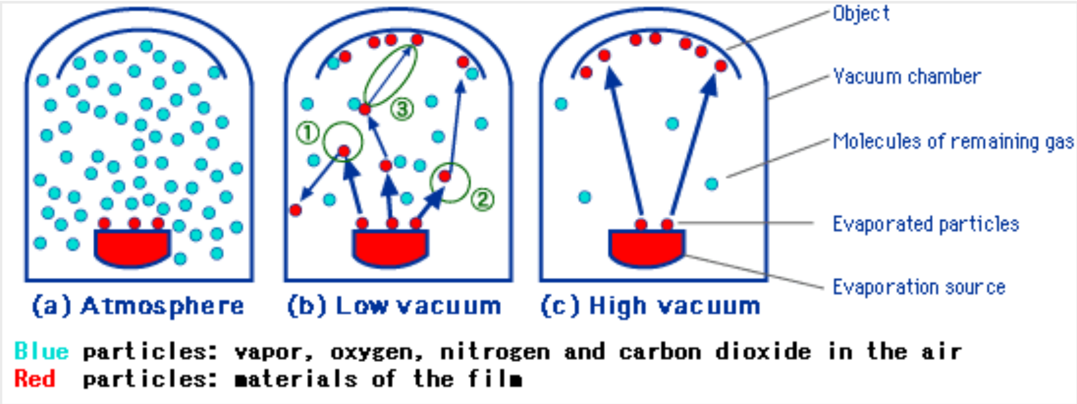
As seen, epitaxial TiN films were directly grown on 2-inch F-mica wafers via a homemade reactive magnetron sputtering using a 2-inch pure titanium (99.999%) target and pure nitrogen (99.999%) reactive gas.

CONCLUSIONS

In summary, high-quality flexible conductive epitaxial TiN films with wafer-scale were synthesized by reactive magnetron sputtering. The crystal structures of TiN films were characterized by XRD, AFM, and STEM, whereas their plasmonic and superconducting properties were measured by SE and electrical transport.

The base pressure of the deposition chamber is ~ 3× 10-8 Torr.

deposition chamber



Now,let guess which information are hidden in these spectrum .

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SQUID (**superconducting quantum interference device**) is a very sensitive magnetometer used to measure extremely subtle magnetic fields, based on superconducting loops containing Josephson junctions.

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Isomorphus(same crystal structure

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A very simple way to think about ……. Is campromise — this is an over simplification indeed .
But its an easy way to start thinking of the parameter space of all these …

Its a compromise between speed and quality .

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Let me emphasise that

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Atom Probe Tomography

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Atomic absorption spectroscopy

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Atomic emission spectroscopy

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X-ray photoelectron spectroscopy

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The crystal quality of the AlN film is normally represented by its FWHM value

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in all articles using this parameter because some groups used FWHM of the rocking curve .

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Nevertheless, other qualities of thin films such as the deposition rate, film thickness, and surface roughness are provided.
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AlN is a unique material in a sense that it has a high mechanical, thermal and chemical stability.

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that sputtered and characterized their AlN thin films for applications in difficult environments. This information will be helpful for the new research that would like to employ this material to make sensors/devices at those conditions.

According to the kinetic theory of molecular gasses, the ions, as well as the neutral species inside the sputtering chamber, have higher kinetic energies at lower process pressure. When they condense and are transformed to the solid state (called adatoms), they land on the surface of the substrate.

One such works worth being mentioned in details herein.

From experimental point of view, this is the easiest parameter to manipulate.

This is a very interesting parameter.

The flow chart in Figure 5 illustrates the roles of major sputtering parameters in depositing c-axis Sensors 2018, 18, 1797 17 of 21
AlN film. This chart is self-explanatory, but two points should be highlighted.

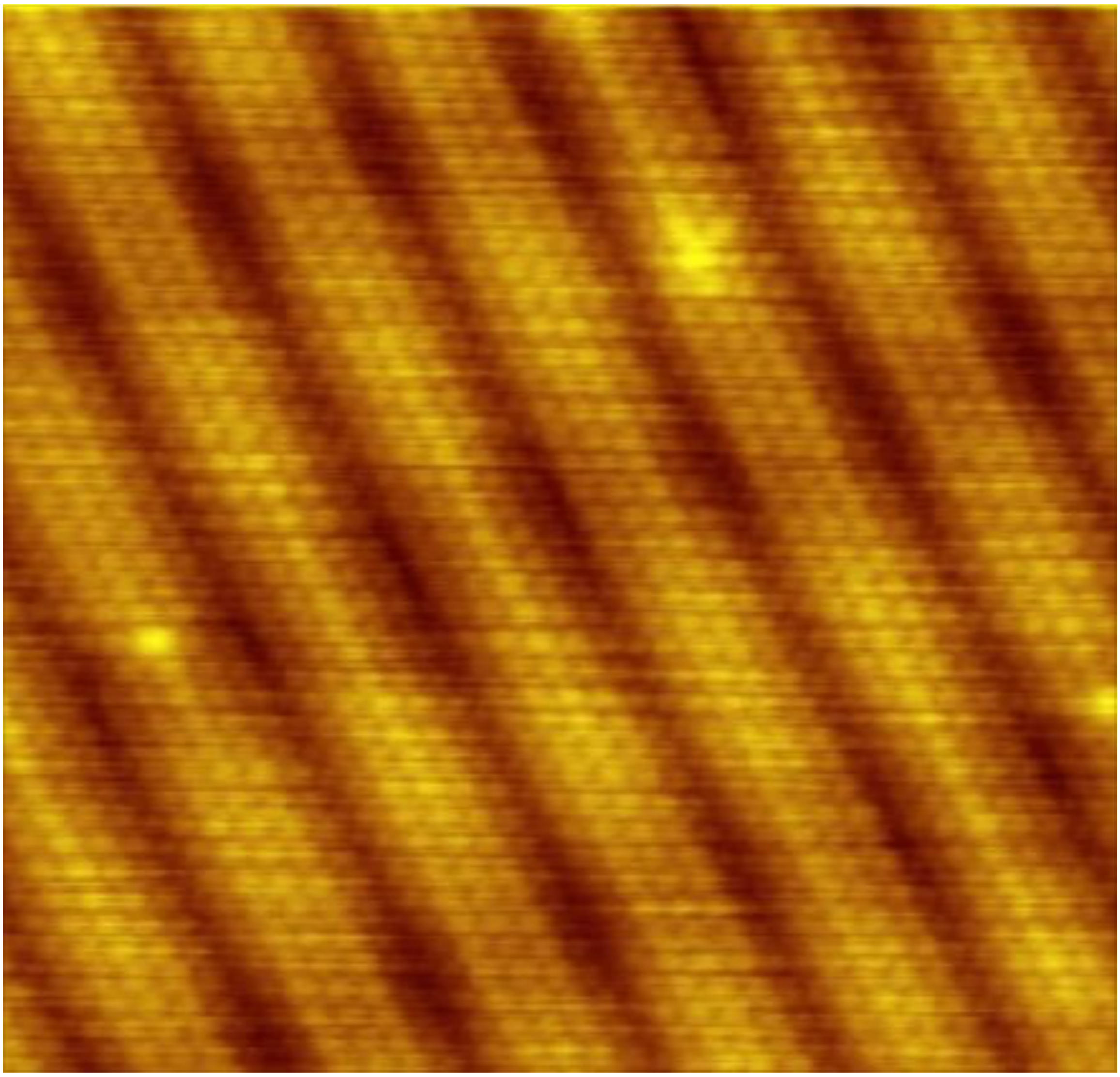

Image of reconstruction on a clean (100) surface of gold.
A **scanning tunneling microscope** (**STM**) is a type of microscope used for imaging surfaces at the atomic level.

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scanning electron microscope (**SEM**) is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that contain information about the surface topography and composition of the sample.

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Spin-polarized scanning tunneling microscopy (**SP-STM**) is a type of scanning tunneling microscope (STM) that can provide detailed information of magnetic phenomena on the single-atom scale additional to the atomic topography gained with STM. —

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SP-STM opened a novel approach to static and dynamic magnetic processes as precise investigations of domain walls in ferromagnetic and antiferromagnetic systems, as well as thermal and current-induced switching of nanomagnetic particles.

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Transmission electron microscopy (**TEM**) is a microscopy technique in which a beam of electrons is transmitted through a specimen to form an image. The specimen is most often an ultrathin section less than 100 nm thick or a suspension on a grid. An image is formed from the interaction of the electrons with the sample as the beam is transmitted through the specimen.

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scanning transmission electron microscope (**STEM**) is a type of transmission electron microscope (TEM). Pronunciation is [stɛm] or [ɛsti:i:ɛm]. As with a conventional transmission electron microscope (CTEM), images are formed by electrons passing through a sufficiently thin specimen. However, unlike CTEM, in STEM the electron beam is focused to a fine spot (with the typical spot size 0.05 – 0.2 nm) which is then scanned over the sample in a raster illumination system constructed so that the sample is illuminated at each point with the beam parallel to the optical axis.

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Die Entropie ist ein Maß für die Unordnung des Systems bzw. unsere fehlende Informa- tion über den Mikrozustand

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Und hier aufgetragen auf axse …

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Scanning probe microscopy is a branch of microscopy that forms images of surfaces using a physical probe that scans the specimen. SPM was founded in 1981, with the invention of the scanning tunneling microscope, an instrument for imaging surfaces at the atomic level.

X-ray fluorescence (**XRF**) is the emission of characteristic "secondary" (or fluorescent) X-rays from a material that has been excited by being bombarded with high-energy X-rays or gamma rays. The phenomenon is widely used for elemental analysis and chemical analysis, particularly in the investigation of metals, glass, ceramics

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Transmission electron microscopy (TEM) is **a high-resolution imaging technique in which a beam of electrons passes through a thin sample to produce an image**. The electron beam is impacted by the sample's thickness/density, composition, and in some cases, crystallinity.

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Films of Aluminum Nitride (AlN) are promising for creation of gas sensors, UV photodetectors, piezoelectric MEMS, and as buffer layers for growth of gallium nitride films. For these applications, it is important to synthesize films with specified orientation.
One of the most promising methods of film synthesis is plasma-activated atomic layer deposition (PEALD). The method allows to increase reactivity of one of the reagents with plasma, and to reduce the deposition temperature significantly. Particularly, study [1] shows successful use of the method for growing c-axis oriented AlN film at the temperatures around 500 °C.
The goal of this study was determining the possibility of AlN film synthesis on Al2O3 substrates via PEALD at temperatures below 300 °C, as well as to figure out how the deposition temperature affects film crystallinity.

Scans for samples grown at 250 and 280 °C also shown reflections of higher order (0004), which purports that higher temperatures result in increase of crystallinity. Presence if this reflection shows higher quality of films grown at higher temperatures.

Then, studies were performed by rocking curve (RC) method, and their results are shown at fig. 2. As can be seen, higher growth temperature, ceteris paribus, changes intensity and shape of RC curve. It means changing microstructure of the films.

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ceteris paribus

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https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7886528

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The magnetoresistance of magnetic tunnel junctions (MTJ) is of great interest, especially for the fabrication of non-volatile magnetic random access memories. Till now, almost exclusively, the MTJ consisted of metal electrodes and an amorphous alumina barrier. Despite large and reproducible tunneling magnetoresistance (TMR), these systems am too complex for a detailed theoretical approach. Most calculations of spin dependent tunneling and TMR were developed for epitaxial MTJ, for a rather restricted choice of materials. For fully epitaxial Fe/(MgO 20 /spl Aring/)/Fe systems, a TMR as high as 2000 % was calculated. Up to now, experimental data on epitaxially grown Fe/(MgO 20 /spl Aring/)/FeCo systems, showed TMR values of only 60%. The development of novel epitaxial systems is of high importance for a broader view on MTJ. In this respect, Fe and Cu nitrides open new and exciting perspectives. Based on good magnetic properties, the Fe nitrides /spl alpha/"-Fe/sub 16/N/sub 2/ and /spl gamma/-Fe/sub 4/N are possible candidates.

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Spin electronic (“spintronic”) devices, based on utilizing the spin as well as the charge of electrons, open up an entirely new class of electronics. Such devices could include nonvolatile magnetic memories, re-programmable logic, and quantum computers. One thing hampering the development of spin electronic devices so far is the lack of sufficiently polarized (nearing 100% spin polarization) current sources for spin injection into semiconductors. Socalled “half-metallic ferromagnets” would circumvent this problem, but true half-metals have proven extremely difficult to realize in practice. However, the phenomenon of spin filtering may also be exploited to create near 100% polarization. Here we propose and demonstrate a different approach [1], combining spin filter tunnel barriers [2] and spin-dependent tunneling [2], similar to a device proposed by Worledge et al. [4]. The combination of a non-magnetic electrode with a spin filter tunnel barrier is used to effectively mimic a half-metallic tunneling electrode and achieve nearly 100% spin polarization. Using this, “artificial half-metal” bilayer, we additionally use a second magnetic electrode, creating a nonmagnetic metal/ferromagnetic insulator/ferromagnetic metal (M-FI-F) device. We utilize EuS as the magnetic insulator, with Gd ferromagnetic and Al nonmagnetic electrodes. The tunnel current in this case depends on the relative magnetization orientation of the EuS filter and the Gd “analyzer,” in analogy to a half-metallic ferromagnet/insulator/ferromagnet tunnel junction. The spin filtering in this configuration yields a previously unobserved magnetoresistance effect, exceeding 100%, suggesting a filtering efficiency close to 100%. The present scheme would also circumvent impedance mismatch problems with semiconducting counter electrodes, and thus potentially allow spin injection from even a non-magnetic metal into a semiconductor.