# A New Type of Memory Based on the RKKY interaction

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# Data centers represent the information backbone of an increasingly digitalized world.

Data centers represent the information backbone of an increasingly digitalized world. Demand for their services has been rising rapidly, and data-intensive technologies such as artificial intelligence, smart and connected energy systems, distributed manufacturing systems, and autonomous vehicles promise to increase demand further. Given that data centers are energy-intensive enterprises, **estimated to account for around 1% of worldwide electricity use,** these trends have clear implications for global energy demand and must be analyzed rigorously. Several oft-cited yet simplistic analyses claim that the energy used by the world's data centers has doubled over the past decade and that **their energy use will triple or even quadruple** within the next decade.

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# ALL CURRENT METHODS OF WRITING AND READING THE DATA INVOLVE USAGE OF ELECTRICAL CURRENT

**Volatile Random-access memory** (RAM; /ræm/) is a form of computer memory that can be read and changed in any order, typically used to store working data and machine code.[A random-access memory device allows data items to be read or written in almost the same amount of time irrespective of the physical location of data inside the memory, in contrast with other direct-access data storage media (such as hard disks, CD-RWs, DVD-RWs and the older magnetic tapes and drum memory), where the time required to read and write data items varies significantly depending on their physical locations on the recording medium, due to mechanical limitations such as media rotation speeds and arm movement. Non-volatile memory (NVM) or non-volatile storage is a type of computer memory that can retain stored information even after power is removed. In contrast, volatile memory needs constant power in order to retain data.

Non-volatile memory typically refers to storage in semiconductor memory chips, which store data in floating-gate memory cells consisting of floating-gate MOSFETs (metal–oxide–semiconductor field-effect transistors), including flash memory storage such as NAND flash and solid-state drives (SSD).

Other examples of non-volatile memory include read-only memory (ROM), EPROM (erasable programmable ROM) and EEPROM (electrically erasable programmable ROM), ferroelectric RAM, most types of Computer data storage devices.

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# PROBLEM WITH DATA CENTERS

The data centers are becoming the biggest consumers of electricity world-wide.

Indeed, data centers are among the highest consumers of electric power. Studies have shown that data center energy consumption continues to increase annually, with two identifiable trends.

The first trend is that mainstream legacy corporate data centers continue to be major consumers of power, despite many organizations migrating systems and hardware to cloud environments. But, while average use is increasing steadily, it's doing so at a lower rate than perhaps 20 years ago when cloud data centers were emerging as a major alternative to legacy facilities.

The other trend is that, while large cloud data centers, often called *hyperscale centers*, are steadily increasing their power usage, they're balancing that increase by investing in green initiatives, such as energy-efficient equipment. They're also revamping supporting systems such as HVAC, security and lighting.

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# RKKY Interaction

RKKY stands for Ruderman–Kittel–Kasuya–Yosida. It refers to a coupling mechanism of nuclear magnetic moments or localized inner d- or f-shell electron spins in a metal by means of an interaction through the conduction electrons.

The theory uses second-order perturbation theory to describe an indirect exchange coupling of conduction spins through the hyperfine interaction, another scenario is for inner electron spins to couple to conduction spins through the exchange interaction.

The theory is based on Bloch wavefunctions and is therefore only applicable to crystalline systems.

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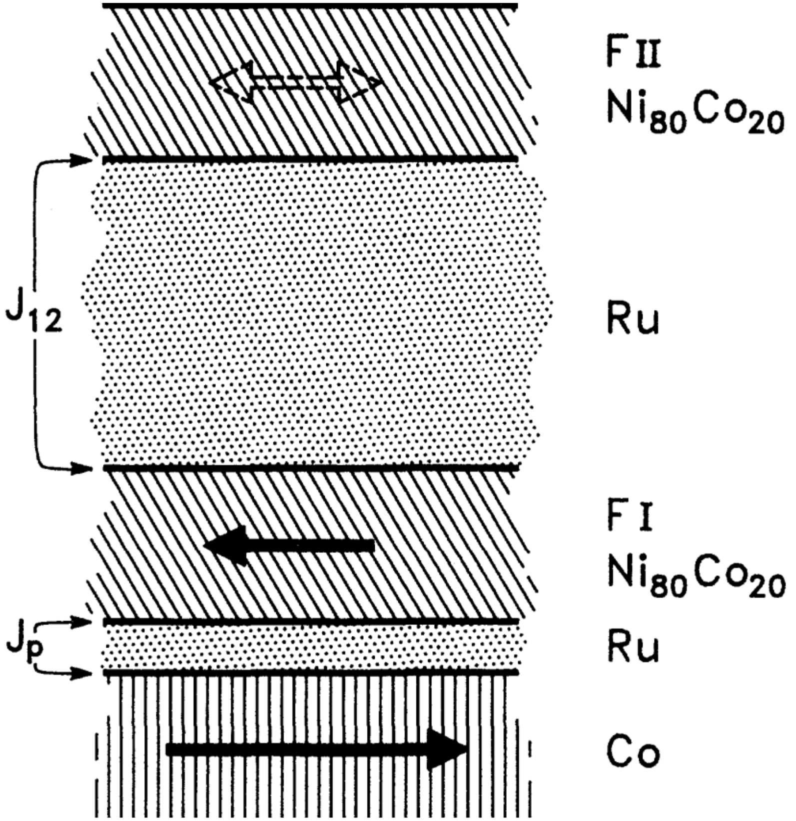
# FIG. 1 illustrates a spin valve comprising two magnetic metals separated by RKKY spacer (normal metal)

Co is AF coupled to Ni $_{80}$ $CO_{20}$ in the limit of ultrathin Ru layers with a coupling strength that rapidly increases as the Ru-layer thickness is decreased to the point ($J_p$ is 3 Á) at which direct coupling through pin holes in the Ru layer overwhelms the AF coupling. And $F_I$ layer is extremely strongly antiferromagnetically coupled to the Co layer. **At $J_{12}$ =12 Á ( FIG. 2) the moments $F_I$ and $F_{II}$ are parallel**, and the overall moment of the structure will be approximately zero. For **$J_{12}$ = 8 Á** FIG. 2) $F_I$ and $F_{II}$ are **anti-parallel,** and the overall moment of the structure will be approximately equal to C0 moment.

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# FIG. 1 , more details.

The exchange coupling, $J_{1,2}$ between two Ni $_{80}Co_{20}$ layers is measured by pinning the moment of one of the Ni $_{80}Co_{20}$ layers (F I) antiparallel to a Co layer.( S. S. P. Parkin et al., *"Spin engineering: Direct determination of the Ruderman-Kittel-Kasuya-Yosida Far-field range function in ruthenium Ru)".* PHYSICAL REVIEW B VOLUME 44, NUMBER 13 1 OCTOBER 1991). The moment of the Co layer is set equal to the sum of the moments of the two Ni $_{80}Co_{2}$layers. This structure can be used as a memory cell for the purposes of the present technology.

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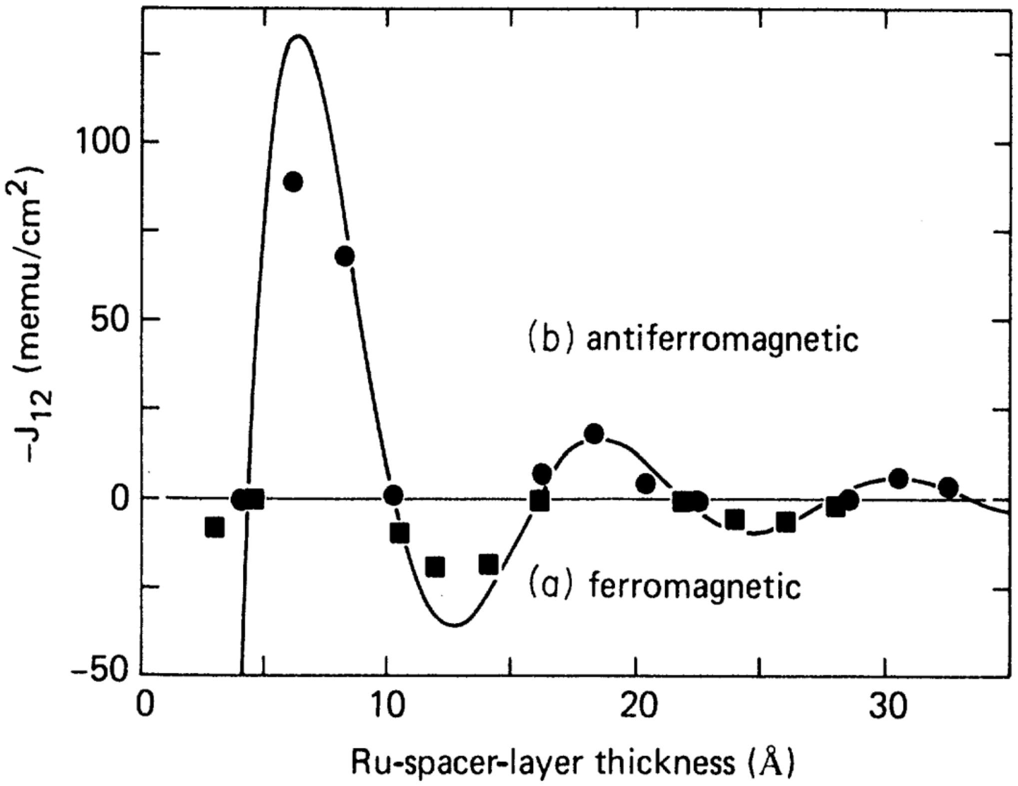
# FIG. 2 shows the Interlayer exchange coupling strength $J_{1,2}$ for coupling of $Ni_{80}Co_{20}$ layers through a Ru spacer layer of spin valve of FIG. 2

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# Memory cell of FIG.1 having two states '1' ($J_{1,2}$ = 8 Å) and '0'( $J_{1,2}$ = 12 Å)

If $J_{1,2}$ between two $Ni_{80}Co_{20}$ layers, as shown in FIG. 2, is **8 Å** , the sign of interaction between two $Ni_{80}Co_{20}$ layers is antiferromagnetic, and the overall magnetization of the magnetic cell comprising the sum of magnetizations of Co, and two $Ni_{80}Co_{20}$ layers is equal to magnetization of just Co as magnetizations of two $Ni_{80}Co_{20}$ layers cancel each other, that is bit'1' can be encoded in such magnetic memory cell configuration.

If, on the other hand, $J_{1,2}$ between two $Ni_{80}Co_{20}$ layers, as shown in FIG. 2, is **12 Å,** the sign of interaction between two $Ni_{80}Co_{20}$ layers is ferromagnetic, and the overall magnetization of the magnetic cell comprising the sum of magnetizations of Co, and two $Ni_{80}Co_{20}$ layers is equal to zero as the magnetization of Co will be cancelled by the magnetizations of two $Ni_{80}Co_{20}$ layers added to each other, that is bit'0' can be encoded in such magnetic memory cell configuration.

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# FIG. 3: Spin Valve irradiated by terahertz radiation

The physics of this effect is based on the idea **that RKKY interaction can also be viewed as a scattering problem**: the equilibrium spin current J flowing through the spacer N is simply related to the RKKY interaction: The characteristic time scale of the system is the time-of-flight τ through the normal spacer N whose thickness is $L_N$: $L_N = v_F \tau$; $v_F$ is Fermi velocity.

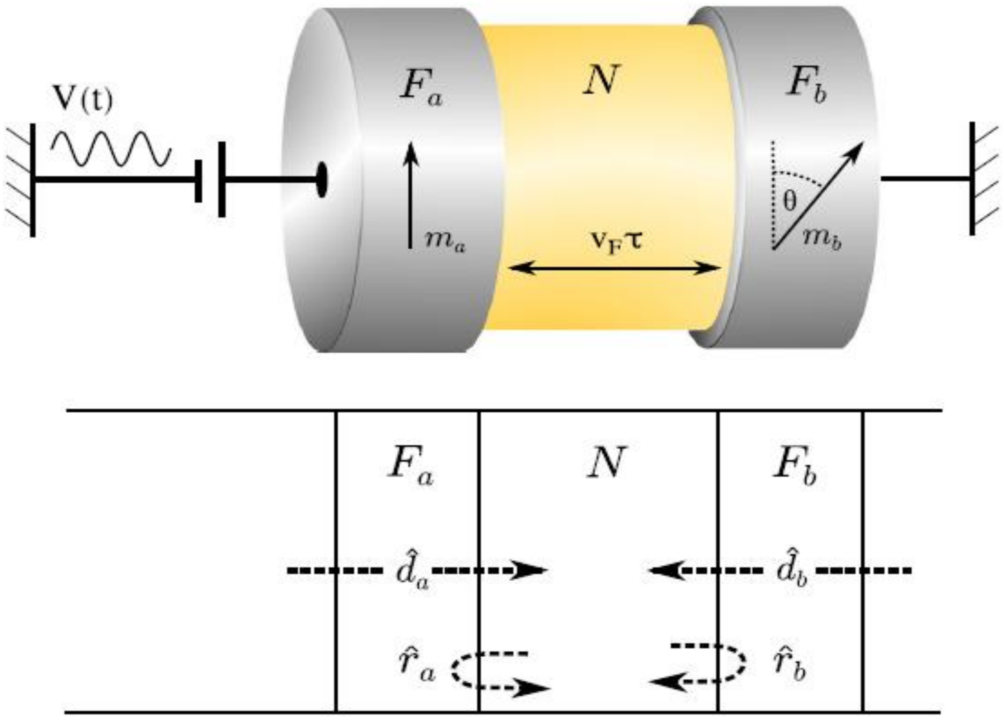


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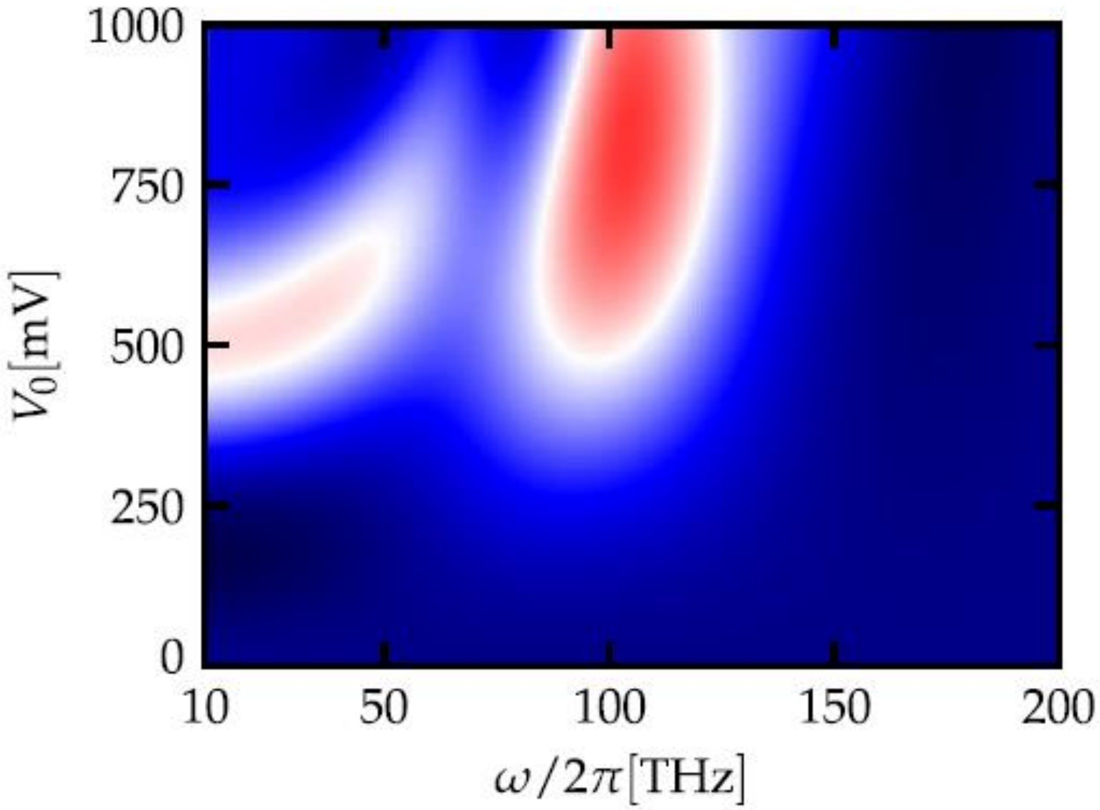
**FIG. 4 THz Radiation can be used to reverse the sign of RKKY interaction by increasing the bias voltage at fixed THz frequency: Red –antiferromagnetic, blue- ferromagnetic.**

"*Control of the Oscillatory Interlayer Exchange Interaction with Terahertz Radiation*", Uta Meyer e al., PRL 118, 097701 (2017) PHYSICAL REVIEW LETTERS week ending 3 MARCH 2017

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# Thus, based on FIG. 4, by applying external terahertz radiation between 10-30 terahertz, we can change the sign of RKKY interaction

This can be done by using Terahertz Magnon Laser invented by Magtera**: US Patent 10,790,635.**

*”Technique of high-speed magnetic recording based on manipulating pinning layer in magnetic tunnel junction-based memory by using Terahertz Magnon laser”*

Though this patent deals with *magnetic tunnel junction-based memory the same approach can be used for RKKY-based magnetic memory. If this is the case, the writing of data will be done with negligible dissipation of energy in memory itself as no external electric current will be used and the usage of THz photons results in the change of RKKY sign without further dissipation in the valve as we affect only the flow of spin current already existing in the system without adding external electric current.*

**The wavelengths of (10-30) THz photons are between ( 10 -30 )µ and the size of spin valve is in 100’s of nanometers, so these photons will have no difficulty to penetrate the spin valve and to enable the required change of the sign of RKKY interaction.**

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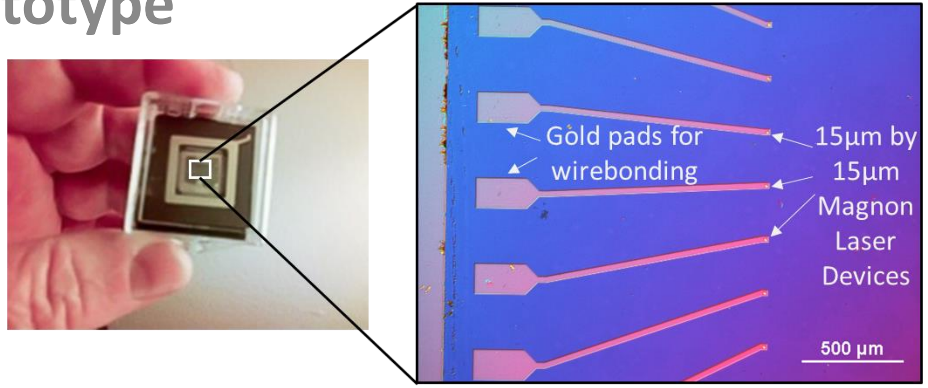
# Magtera’s THz Breakthrough: FIG. 5 depicts Magnon Laser

prototype




**Broadly tunable, using voltage:**
1 to 30 THz
**Narrow Linewidth:**
**Schawlow–Townes limit=>**
5 MHz (Practically- several kHz)
**Milliwatt (and greater) output power**
**Compact, chip-scale device**
**Room temp operation**
**Low cost wafer-scale production (similar to MRAM)**

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# TRANSISTOR REVOLUTION

If every transistor in a modern CPU is to be replaced with an old vacuum tube, how much power would that CPU take?

Each transistor in a modern CPU uses, very roughly, less than 1 microwatt. A vacuum tube would require (also very roughly) a watt to do the same job.

A modern CPU might have several billion transistors and uses around 100 watts. If you could duplicate that with vacuum tube you would need 1000 megawatts of power, or more. Plan on building a really large nuclear power plant next door to your CPU.

**6 orders of magnitude-between replacing  a vacuum tube ( 1 watt)  with a transistor (0.1 microwatt) => 10 million times lower power**

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# The case for THz-based write/read of RKKY-based memory revolution

Let us compare the energy dissipated by each conventional memory cell during the read-write operation with the proposed THz-based reading/ writing of data with negligible energy dissipation in the RKKY-based memory cell.

Indeed, the minimum switching energy of the field-assisted cell is 0.054 pJ/bit with a corresponding switching latency of 618 ps=> $P_{(W)}=E_{(J)}/t_{(s)}$ => . $10^{-13}$ Joule/bit latency switch time $10^{-9}$ => $10^{-4}$ watt= 100 microwatts

**For the RKKY based memory we need one THz photon during time period of modulation frequency to read /write data bit; for 30 THz => $10^{-20}$ joule/$10^{-9}$= $10^{-11}$ watt=>10 million times lower power.**

**So, the same order of magnitude difference – 6 orders of magnitude-between replacing a vacuum tube ( 1 watt) with a transistor (0.1 microwatt) => 10 million times lower power.**

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## The same kind of revolution needs the data-driven modern society

that needs the data centers to replace the memory cells to sustain the exponential increase of data generation and exchange consistent with available energy sources and minimizing the energy dissipation in the memory itself

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