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NOVEL TECHNIQUE OF HIGH-SPEED MAGNETIC RECORDING

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CONVENTIONAL MEMORY CELL- MAGNETORESISTIVE RANDOM-ACCESS MEMORY (MRAM)

Example 1

Magnetoresistive random-access **memory** (**MRAM**) is a type of non-volatile random-access memory which stores data in magnetic domains. Developed in the mid-1980s, proponents have argued that magnetoresistive RAM will eventually surpass competing technologies to become a dominant or even universal memory. Currently, memory technologies in use such as flash RAM and DRAM have practical advantages that have so far kept MRAM in a niche role in the market.

MRAM CELL

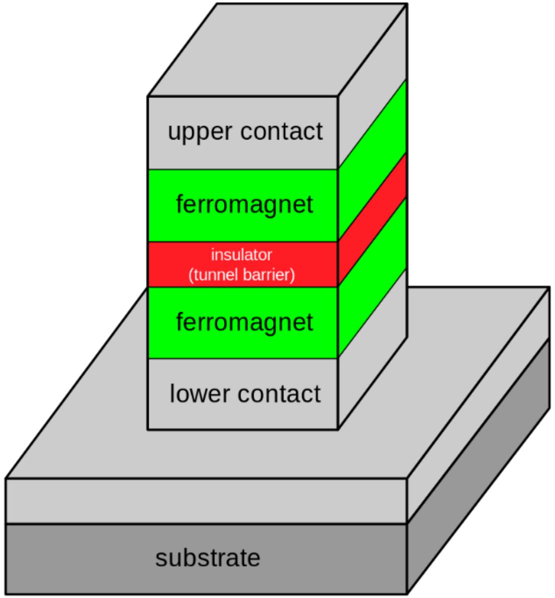
Unlike conventional RAM chip technologies, data in MRAM is not stored as electric charge or current flows, but by magnetic storage elements. The elements are formed from two ferromagnetic plates, each of which can hold a magnetization, separated by a thin insulating layer. One of the two plates is a permanent magnet set to a particular polarity; the other plate's magnetization can be changed to match that of an external field to store memory. This configuration is known as a magnetic tunnel junction and is the simplest structure for an MRAM bit. A memory device is built from a grid of such "cells". The conventional implementation of MRAM is based on **magnetic tunnel junction** (**MTJ**).

MAGNETIC TUNNEL JUNCTION (MTJ)

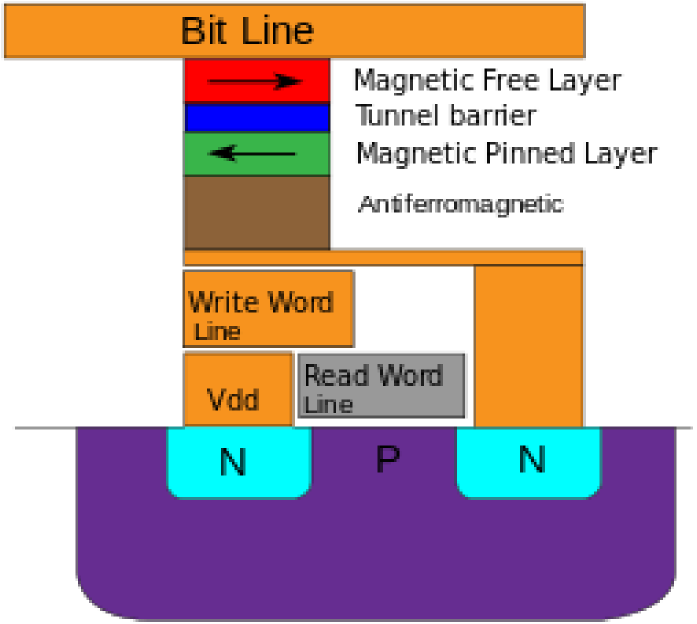
Tunnel magnetoresistance (**TMR**) is a magnetoresistive effect that occurs in a **magnetic tunnel junction** (**MTJ**), which is a component consisting of two ferromagnets separated by a thin insulator. If the insulating layer is thin enough (typically a few nanometers) electrons can tunnel from one 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.

MTJ


upper contact
ferromagnet
insulator
(tunnel barrier)
ferromagnet
lower contact
substrate

Simplified structure of MTJ-based MRAM cell



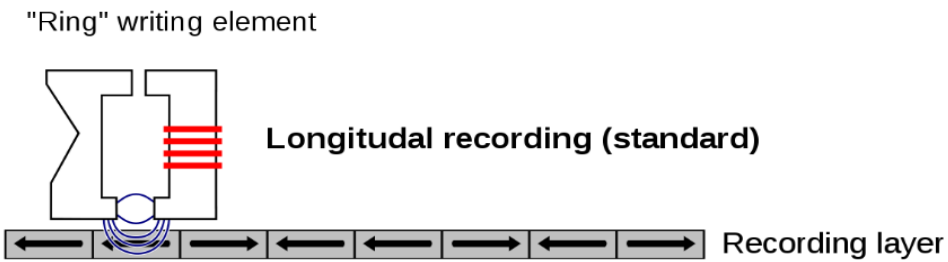
Reading from MRAM cell.

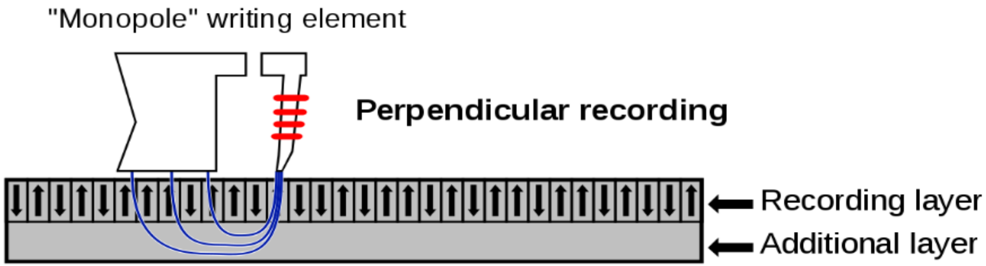
The simplest method of reading is accomplished by measuring the electrical resistance of the cell. A particular cell is (typically) selected by powering an associated transistor that switches current from a supply line through the cell to ground. Because of tunnel magnetoresistance, the electrical resistance of the cell changes with the relative orientation of the magnetization in the two plates. By measuring the resulting current, the resistance inside any particular cell can be determined, and from this the magnetization polarity of the writable plate. Typically if the two plates have the same magnetization alignment (low resistance state) this is considered to mean "1", while if the alignment is antiparallel the resistance will be higher (high resistance state) and this means "0".

Conventional Recording (Writing) into MRAM cell.

Data is written to the cells using a variety of means. In the simplest "classic" design, each cell lies between a pair of write lines arranged at right angles to each other, parallel to the cell, one above and one below the cell. When current is passed through them, an induced magnetic field is created at the junction, which the writable plate picks up. This pattern of operation is similar to magnetic-core memory, a system commonly used in the 1960s. This approach requires a fairly substantial current to generate the field, however, which makes it less interesting for low-power uses, one of MRAM's primary disadvantages. Additionally, as the device is scaled down in size, there comes a time when the induced field overlaps adjacent cells over a small area, leading to potential false writes. This problem, the half-select (or write disturb) problem, appears to set a fairly large minimal size for this type of cell.

Conventional Longitudinal recording and **perpendicular recording**.





CONVENTIONAL LONGITUDINAL RECORDING IS BASED ON THE TUNNEL MAGNETORESISTANCE (TMR) EFFECT

In longitudinal recording, a magnetic head writes by changing the magnetic field that is parallel to the surface of the magneto resistive random-access memory or MRAM. The change of the magnetic field causes the change of the orientation of the magnetic bit of the recording layer. This process is based on the tunnel magnetoresistance (TMR) effect. Its advantage is non-volatility, low power usage, and good shock robustness. The 1st generation that was developed was produced by Everspin Technologies and utilized field induced writing.

MRAM Technology Attributes Archived, June 10, 2009, at the Wayback Machine.

Spin-transfer torque (STT)

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. This can be used to excite oscillations or even flip the orientation of the magnet. The effects are usually seen only in nanometer scale devices.

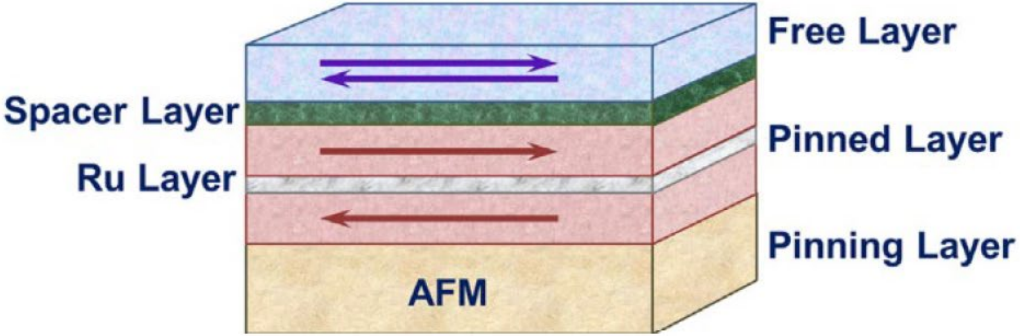
PERPENDICULAR RECORDING IS BASED ON THE SPIN-TRANSFER TORQUE (STT)

The perpendicular recording is based on the spin-transfer torque (STT) on which Crocus, Hynix, IBM, and several other companies are working. In this type of recording the magnetic field generated by monopole writing element varies in the direction perpendicular to the surface of the cell of the recording layer.

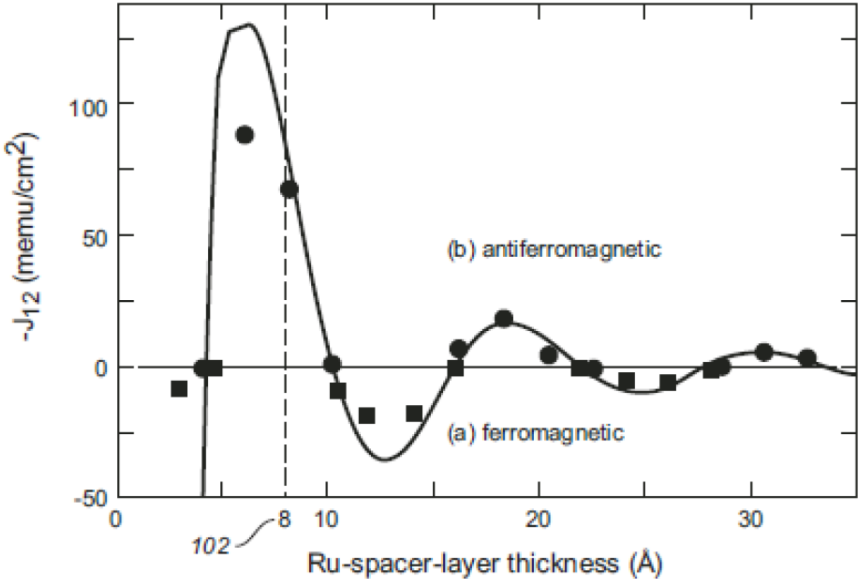
The Main Idea

The Main Idea of the present invention is to use the Terahertz Magnon Laser to manipulate an RKKY-based spacer in a conventional memory cell to provide for a very fast recording capability

Magnetic cell including RKKY Ru layer



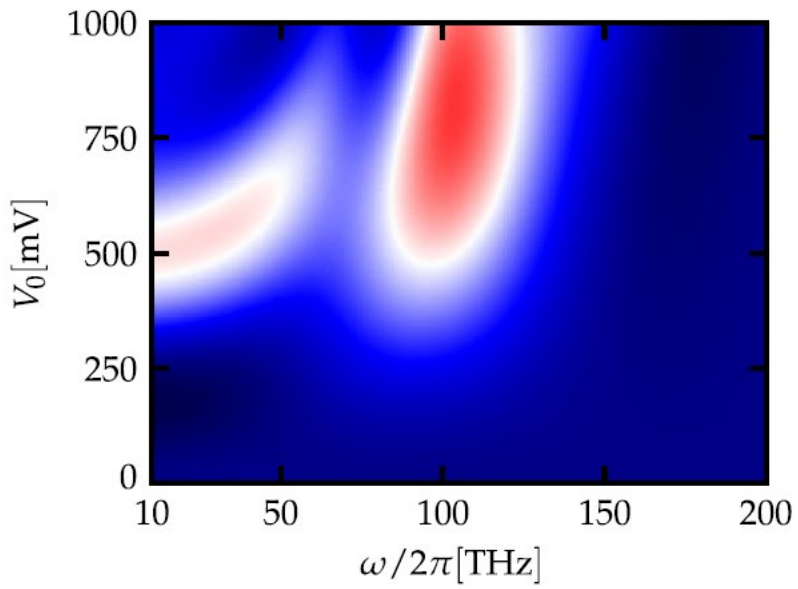
Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction for the Ruthenium (Ru) spacer



Control of the Oscillatory Interlayer Exchange Interaction with Terahertz Radiation

The oscillatory interlayer exchange interaction between two magnetic layers separated by a metallic spacer (RKKY interaction) is one of the few coherent quantum phenomena that persists at room temperature. It was shown that this interaction can be controlled dynamically by illuminating the sample (e.g. a spin valve) with radiation in the (10-100) THz range. It was predicted that the exchange interaction could be changed from ferromagnetic to anti-ferromagnetic (and vice versa) by tuning the amplitude and/or the frequency of the illuminating radiation. The chief theoretical result was an expression that related the dynamical exchange interaction to the static one that has already been extensively measured.

THz Radiation can reverse the sign of RKKY interaction. The color code goes from dark blue (antiferromagnetic) to red (ferromagnetic). Vo is the amplitude of THz radiation



"Control of the Oscillatory Interlayer Exchange Interaction with Terahertz Radiation", Uta Meyer, Géraldine Haack, Christoph Groth, and Xavier Wainta; Phys. Rev. Lett. 118, 097701 – Published 3 March 2017.

Magtera, Inc. has patented the use of Terahertz Magnon Laser to manipulate an RKKY-based spacer in a conventional memory cell to provide for a very fast recording capability.

Magtera, Inc. has patented the use of Terahertz Magnon Laser (U.S. Patent Application No. 16/245,224 titled "TUNABLE MULTILAYER TERAHERTZ MAGNON GENERATOR" and filed on 1/10/2019; and U.S. Patent Application No. 16/245,247 titled "TERAHERTZ MAGNON GENERATOR COMPRISING PLURALITY OF SINGLE TERAHERTZ MAGNON LASERS") to manipulate an RKKY-based spacer in a conventional memory cell to provide for a very fast recording capability.

U. S. Patent application No. 16/ 704090, titled "NOVEL TECHNIQUE OF HIGH-SPEED MAGNETIC RECORDING BASED ON MANIPULATING PINNING LAYER IN MAGNETIC TUNNEL JUNCTION-BASED MEMORY BY USING TERAHERTZ MAGNON LASER" and filed on 5/12/2019.

Employing the THz Magnon Laser as an optical writing head

More specifically, we use the THz Magnon Laser as an optical writing head for longitudinal recording by changing the orientation of a single memory cell on the recoding layer. The change of the orientation is achieved by changing the exchange interaction sign from ferromagnetic to antiferromagnetic and vice versa of the RKKY spacer (Ru spacer) of the MTJ memory cell.

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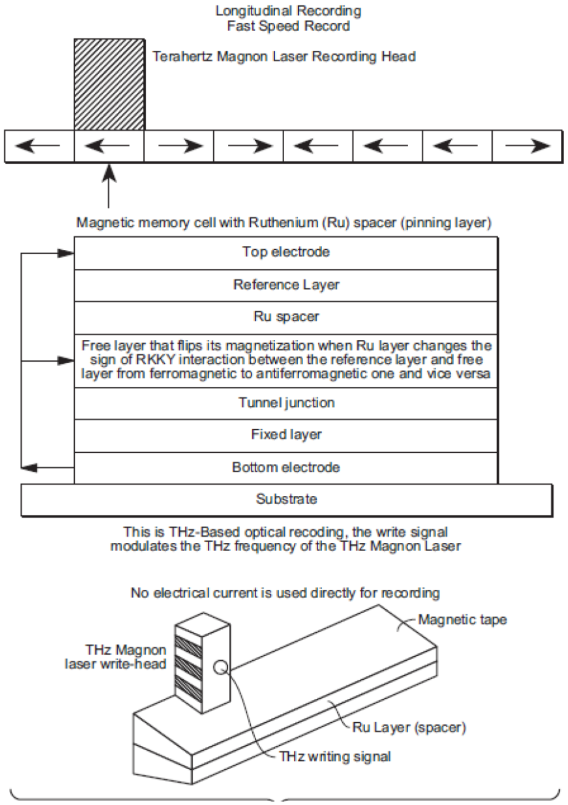
Implementation of new high-speed recording by using THz optical writing head



Implementation of new high-speed recording by using THz optical writing head

The memory cell comprises a substrate, a bottom electrode, a fixed layer, a tunnel junction, a free layer, a Ru spacer, a reference layer, and a top electrode.

The free layer flips its magnetization when the RKKY spacer changes the sign of its RKKY interaction between the reference layer and free layer from ferromagnetic to antiferromagnetic and vice versa.

This can be done by illuminating the memory 154 by using the Terahertz Magnon laser recording head that generates the terahertz writing (or recording) signal in the range between (10 and 100)THz as was explained above.

The physics of THz Magnon Laser

The physics of THz Magnon Laser was disclosed in US Patent 7,508,578.

In the U. S. Patent Application Serial, No: 16/245,224 ,filed on January 10, 2019 and entitled “TUNABLE MULTILAYER TERAHERTZ MAGNON GENERATOR” the voltage-based tuning of the Magnon laser was disclosed.

It was shown, that the bias voltage ǒV applied between the top electrode and the bottom electrode across at least one multilayer tunable microcolumn is configured to shift the Fermi level of the spin injector with respect to the Fermi level of the ferromagnetic material. The minority electrons having spin down are injected into the Magnon Gain Medium from the spin injector by tunneling via the tunnel junction after the Fermi level of the spin injector is shifted with respect to the Fermi level of the ferromagnetic material are configured to generate non-equilibrium magnons in the Magnon Gain Medium resulting in generation of terahertz radiation.

The tuning of THz Magnon LASER

The tuning of the THz Magnon Laser can be achieved by changing the bias voltage $eV_{bias} = (D+ \varepsilon_p)$ by dV. It will result in changing the lasing frequency (tuning) by df:

$(df/f) =-(dV/V)\ (\Delta/\varepsilon_p)^{1/2}$

Thus, the tuning of lasing frequency is parametrically larger than the shift in bias voltage because small changes in bias result in large changes in the electron energy and therefore in large changes in lasing frequency. Thus, we can cover the whole THz band in the range of (1 – 30) THz by using voltage- based tuning.

The high-speed longitudinal recording using THz Magnon Laser head on the memory cell including RKKY enabled spacer

The high-speed longitudinal recording using THz Magnon Laser head on the memory cell including RKKY enabled spacer is achievable by controlling the magnetic configuration (e.g. parallel versus anti-parallel) of a spin valve by varying the intensity or the frequency of generated terahertz radiation.

The steps:

(a) Applying a writing signal as a bias voltage signal to the Terahertz Magnon laser head, thus generating the THz radiation with modulated THz frequency, whereas the modulated frequency corresponds to the writing signal;

(b). Illuminating the RKKY spacer (for example Ru spacer, can be other spacers, like Cu, etc.) by modulated THz signal thus causing the RKKY interaction to change its sign from antiferromagnetic to ferromagnetic (and vice versa) in accordance with the THz writing signal whereas the magnetic tape including a plurality of magnetic cells becomes the recording medium, and whereas the magnetic cell is located in such geometrical position in relation to THz Magnon Laser writing head that THz radiation illuminates the Ru spacer.

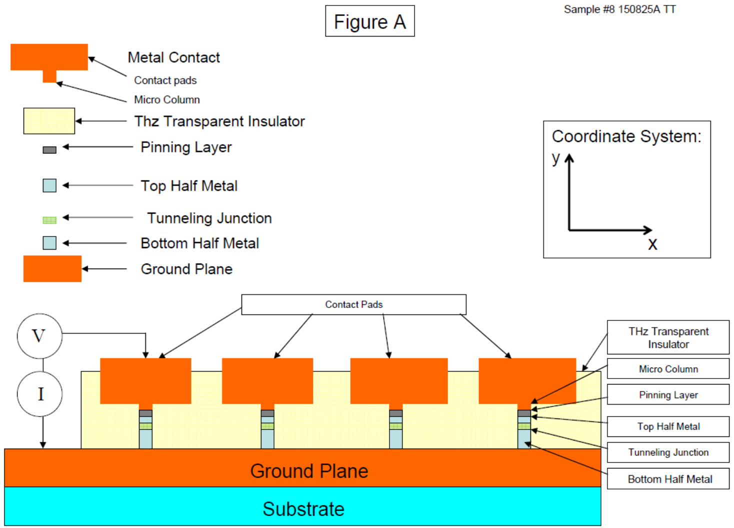
The reading can be done by using a conventional head

The reading can be done by using a conventional head that utilizes the tunnel magnetoresistance (TMR) effect. Thus, the reading takes place at the conventional speed, but writing can be done 10^3 times faster than by using the conventional methods.

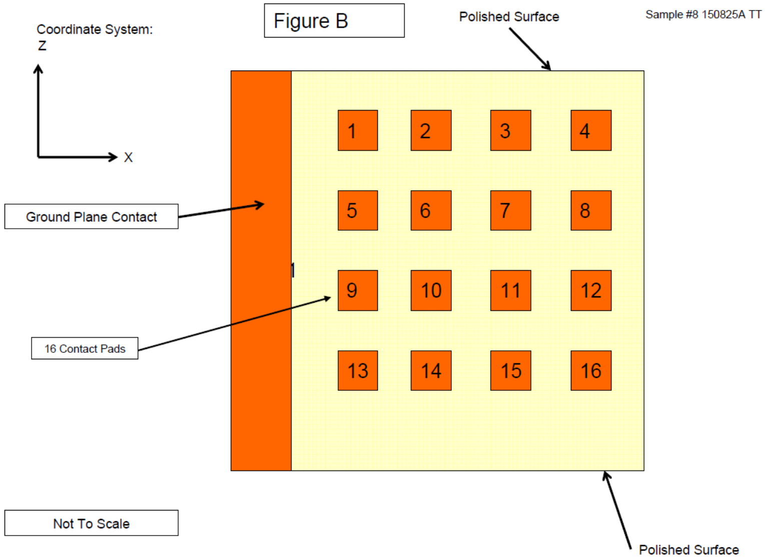
Example: high speed recording of large data sets for AI and data mining.

Data mining is the process of discovering patterns in large data sets involving methods at the intersection of machine learning, statistics, and database systems. Data mining is an interdisciplinary subfield of computer science and statistics with an overall goal to extract information (with intelligent methods) from a data set and transform the information into a comprehensible structure for further use. Data mining is the analysis step of the "knowledge discovery in databases" process, or KDD. Aside from the raw analysis step, it also involves database and data management aspects, data pre-processing, model and inference considerations, interestingness metrics, complexity considerations, post-processing of discovered structures, visualization, and online updating. The difference between data analysis and data mining is that data analysis is used to test models and hypotheses on the dataset, e.g., analyzing the effectiveness of a marketing campaign, regardless of the amount of data; in contrast, data mining uses machine-learning and statistical models to uncover clandestine or hidden patterns in a large volume of data. To create large volumes of data for further processing the high-speed recording can be of major importance and usage.

TERAHERTZ MAGNON LASER- side view



TERAHERTZ MAGNON LASER- top view



TERAHERTZ MAGNON LASER
single multicolumn