Applications for antiferromagnets

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Today, spintronics from geo to nano

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Very fast recent development
2014
Jakub Železný et al.
2016

Peter Wadley et al.
2016
USB device
```matlab
fwrite(comm, 51); pause(0.5); % warming up comm
fwrite('Buffer bytes:'); fwrite(comm.BytesAvailable);
disp('Ready.'); pause(0.5);

% Warm up pulses
fwrite(comm, 50); % "0"
disp('Initializing...');
fwrite(comm, 50); % "0"
pause(5)

% The long loop is here...
counts = 0;
beats = 0;
for n = 1:5; % number of switches
    % Writing #0
    pause(1);
    state = 1;
    fwrite(comm, 49); % "0"
    for k = 1:10
        pause(0.5);
        counts = counts + 1;
        if k == 2
            reading; % reading
        end
    end
end
```
2016
USB-powered portable AFM lab
Why a portable device is important

Without

With
You detect improvements when you **use** things
Costs

Budget, 1m 2y

Time
You detect improvements when you use things

External example: graphene flagship

Chairman of the Executive Board is Vittorio Pellegrini, IIT, Italy. Co-owner of Bedimensional.
Remarkable features of antiferromagnetic spintronics
Current density was fixed at $2.7 \times 10^7 \text{ A cm}^{-2}$

Pulse length: 200 $\mu$s – 1 ms

**Multiple stable intermediate states**
1000+ intermediate states

Quickest pulse 250 ps

Easy to linearize output

September 2016
250 ps pulses
Count over $2^{10}$
Easy to linearize output
Vivien Schuller here
So what?
One AFM cell is an incremental counter.
Packaging
CuMnAs cross
Principle of operation
Counting mode

Input

MODE

V_read

OUT 1

GND

OUT 2
Reading mode

Input

MODE

V_{\text{read}}

OUT 1

GND

OUT 2
Increment/Decrement mode
Hybrid encapsulation

Input

MODE

$V_{\text{read}}$

OUT 1

DEC

INC

GND

OUT 2
A stand-alone component that receives inputs and reports an electrical voltage. If you wish, you could add linearization, amplification, counter filing flags, ...
We had 13 transistors, we need 10 for 2 AFMEM counters

8 pin chip carrier: could contain 2 AFMEM counters
We placed components only on one side

We used 2 layer routing
Subtle features

Non-volatile spin-based retention

Small currents or a direct path to ground won’t discharge
Piezoelectric impulses are oscillatory and leak to ground

These won’t erase the information in AFMEM.
Passive traffic flow monitoring

3 colors updated each 10 seconds.
(Let it be inaccurate and low-capacity!)
The integrated piezoelectric signal classifies the vehicles
Passive vehicle classification

The integrated piezoelectric signal classifies the vehicles.
Passive vehicle classification

The AFMEM passively integrates (analyzes) the data
Can read voltages
Can switch transistors
Can redirect $V_{read}$ voltages
Can push information further
Can reset the integrator

Electrically passive

Switch on on-demand
What about high-frequencies?

250ps pulses
Commercial pulse counters

Typically:

**PRICE:**
< 1 euro

**RANGE:**
one unit 8-16 bits
(2^10 = 1024)
(2^16 = 65536)
Easy to concatenate!

**MAX FREQUENCY:**
10 - 40 MHz
Can we do better than this?

AFM not even at its limits for 250 ps pulses

Bridge between THz and MHz

“Slow” electronics can revisit each “1 ms”
Commercial pulse counters

Measuring time

Measuring velocities!

Measuring distances (time of flight)

Example: $D = \frac{c}{2} \times (\text{number of pulses})$

Consumer electronics,
Civil engineering and infrastructure risk,
Military and security.
SF02 Laser Rangefinder – 50 m

$349.00

Product ID: 28043
In Stock: 14

Quantity: 1
Add to cart

1-9
$349.00

10+
$314.10
7 Downloads
How can we become competitive in the short-term?
Incremental progress in complexity
Getting closer to solutions

A thermometer component costs 1 EURO

“Adding an antenna” of €5 increases the value of the product by €50+ euros

INTERNET = ADDED VALUE

LOW ACCESS FEE

COMPONENT
< DEVICE
< SOLUTION
Recycle know-how

Technological
Know how

Market
know-how
AFM spintronics won’t be *perfect* the first day
Not the best camera
GoPRO® sold $1.5 billion in 2015
AFM spintronics won’t be *perfect* the first day,
but we are moving.