ELEMENTAL GIANT MAGNETORESISTANCE (GMR) SENSORS FOR NEUROMORPHICAL APPLICATIONS
Càndid Reig received the B.Sc., M.Sc., and Ph.D. degrees in Physics from the University of Valencia, Valencia, Spain, in 1994, 1995, and 2000, respectively. In 1997, he was with Radiaciones y Microondas S.A., Madrid, Spain. He joined the Department of Applied Physics, University of Valencia, where he developed his doctoral thesis. In 2001, he was an Assistant Professor with University Miguel Hernández, Elche, Spain. In 2002, he was an Assistant Professor with the University of Valencia and a Post-Doctoral Fellow with INESC-MN, Lisbon, Portugal, working on sensors integration. He is, since 2007, an Associate Professor with the Department of Electronic Engineering, University of Valencia, where he teaches and does research. His current research interests include the development of printed antennas as well as sensors (mainly gas and magnetic) integration at the integrated circuit level. He has also served as external consultant for Analog Devices during 2013 and 2015.

He has been a researcher and principal investigator in different national and international scientific research projects. He has advised 3 PhD students within these topics. He has published more than 40 journal papers, contributed more than 50 works to conferences, edited a book, and co-authored six book chapters. Dr. Reig actively participates in periodic international conference program committees, in research journals’ editorial boards as well as acting as a referee for different research journals. He was the General co-Chair of ENICS (Valencia, 2007), the IEEE Sensors Conference (Valencia, 2014), MIC-Sensors (Valencia, 2020) and he is currently the Chair of the Spanish Chapter of the IEEE Sensors Council. He was a co-recipient of the IETE-J C Bose Memorial Award in 2011 and the MSJ Best Publication Award in 2014.
VISION SENSORS

EVENT DRIVEN (ED) VS. FRAME DRIVEN (FD)

- Standard artificial vision sensors use arrays of optical sensors (such as photodiodes) for capturing an image (frame) by sequentially reading of each element of the array (pixel).

- **Bioinspired (neuromorphic / retinomorphic)** artificial vision sensors try to mimic the biological vision process by integrating vision sensors with asynchronous parallel computing (such as artificial neural networks).

- As a result, serial “spiking” signals are produced for coding the image in an event driven approach.

Advantages of the ED approach

- Using asynchronous schemes
- Easier serialization.
- Higher processing speed.

The same paradigm can also be applied for other biological senses to provide auditory and olfactory ED sensors.
Standard CMOS technologies provide routes for the integration of solid state sensors with processing. Many different implementations of address event representation (AER) can be found. The Selective Change Driven (SCD) approach will be considered.

**Definition of SCD sensor**

An SCD sensor delivers, under requirement, the illumination level and the address of the pixel with the highest change since the last reading.

**Advantages of the ED approach**

- Optimal use of the processor
- The illumination output is an output.
- Pixels with high changes are always read.

For implementing an SCD sensor on a standard CMOS technology, two circuits need to be considered:

- **Winner-Take-All (WTA)**, for selecting the highest magnitude change (analog).
- **Pixel addressing circuit**, for identifying the pixel with the highest magnitude change (digital).

The same scheme can also be applied for other sensors apart from vision sensors.
OBJECTIVE

Developing Giant Magnetoresistance (GMR) sensors for Adress Event Representation (AER) applications
**WHAT IS GMR?**

**GMR = GIANT MAGNETORESISTANCE**

Giant MagnetoResistance

GMR is a significant change of the resistance with the external magnetic field observed in **multilayered structures** at room temperature.

\[ MR = \frac{R_{\uparrow\downarrow} - R_{\uparrow\uparrow}}{R_{\uparrow\uparrow}} \]

Digital applications

Analog applications

**Magnetic field measurement**
- Biotechnology
- Compass
- Angle measurement
- Traffic control
- Space applications
- Electric current measurement

**Properties**
- High sensitivity
- Measurement of in-plane fields
- High scale of integration
- Design flexibility
- Compatibility with CMOS

**Nobel Prize in Physics (2007)**

A. Fert

P. Grunberg
**LINEAR GMR STRUCTURES**

**SPIN VALVES – CROSSED AXIS**

Spin Valve (SV)

Typical SV device

Typical SV structure

Microfabrication process

\[ R = R_0 + M_{R_L} \cdot B \]
APPLICATION RANGE

MAGNETIC FIELD SENSING

<table>
<thead>
<tr>
<th>Magnetic Field Range</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 pT</td>
<td>human brain</td>
</tr>
<tr>
<td>25 µT</td>
<td>magnetic tape</td>
</tr>
<tr>
<td>30-60 µT</td>
<td>earth field</td>
</tr>
<tr>
<td>5 mT</td>
<td>fridge magnet</td>
</tr>
<tr>
<td>1 T</td>
<td>loudspeaker magnet</td>
</tr>
</tbody>
</table>

- SQUID
- Search coil
- Optical pumping
- Nuclear presession
- Fluxgate
- AMR
- Optical fiber
- GMI
- Magneto optical
- MTJ
- Magnetostriction
- EMR
- GMR
- Hall
- Magnetic transistor
- Magnetic diode

Magnetic field range: $1 \times 10^{-12}$ T to $1 \times 10^3$ T
OUTLINE

- Introduction
- Implementation
- Results
- Conclusions
**WINNER TAKE ALL (WTA) CIRCUITS**

**LAZZARO’S CELL**

PMOS implementation

\[ V_{DS}^{M1j} \uparrow \quad M1j \quad M1j \quad I_cj \quad Vcom \quad Vcom \quad I_{ck} \quad \]

\[ V_j \downarrow \quad I_{sj} \quad I_{sk} \quad \]

sensors (e.g. photodiodes)

Simulated response (AMS 0.35 um)

\[ W_1 = W_2 = 20 \, \mu m \]
\[ L_1 = L_2 = 10 \, \mu m \]
\[ I_{com} = 20 \, \mu m \]

\[ \begin{align*}
W &= 20 \mu m \\
L &= 10 \mu m \\
I_{com} &= 20 \mu m
\end{align*} \]

resolution: 50 nA
INCLUDING RESISTIVE SENSORS

WITHIN THE LAZZARO’S CELL

Integration of GMR sensors

Simulated response

resolution: ~10% (1 kΩ)
GMR SENSORS DESIGN

MASKS SET

1x8 sensing elements

$R_0 \sim 1\ k\Omega$

1x8 sensing elements (with current strips)

$R_0 \sim 5\ k\Omega$

ELEMENTAL GMR SENSORS FOR NEUROMORPHIC APPLICATIONS
OUTLINE

- Introduction
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Elemental GMR Sensors for Neuromorphic Applications

GMR Sensors Designs

Chips

R₀ ~ 5 kΩ

R₀ ~ 1 kΩ

Sensor active region

Sensor Devices 2020

C. Reig

València, 2020
STATIC CHARACTERIZATION

MAGNETIC FIELD

Experimental setup

Results

Automatized measurement GPIB/LabView

\[ R_0 [\Omega] \quad MR [%] \]

1165±5 \quad 1,66±0.04

<table>
<thead>
<tr>
<th>Magnetic field (Oe)</th>
<th>Normalized resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>-4</td>
<td>0.994</td>
</tr>
<tr>
<td>-3</td>
<td>0.998</td>
</tr>
<tr>
<td>-2</td>
<td>1.000</td>
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<td>1.004</td>
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<tr>
<td>1</td>
<td>1.006</td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>
MAGNET DETECTION
AS A FUNCTION OF THE POSITION

Elemental GMR Sensors for Neuromorphic Applications
OUTLINE

- Introduction
- Implementation
- Results
- Conclusions
CONCLUSIONS

... AND FUTURE WORK

- GMR can be integrated within basic WTA circuits in AER approaches.
- Preliminary results are promising

- Application on magnetic field scanning will be evaluated in the near future. GMR/TMR sensing arrays will be considered.
Thank you!

**ELEMENTAL GIANT MAGNETORESISTANCE (GMR) SENSORS FOR NEUROMORPHICAL APPLICATIONS**

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