Collaborative project*

Project acronym: SNM

Project full title: "**Single Nanometer Manufacturing for beyond CMOS devices**"

Grant agreement no: 318804

Deliverable: 12.4 ("SNM slide presentation for publication & EC public presentation")

Name of the coordinating person: Prof. Dr. Ivo W. Rangelow, Email: ivo.rangelow@tu-ilmenau.de

List of participants:

Participant no.	Participant organisation name	Part. short name	Activity Type	Country
1 (Co)	Technische Universität Ilmenau	**TUIL**	HER	Germany
2	EV Group E. Thallner GmbH	**EVG**	IND; End-user	Austria
3	IMEC	**IMEC**	RES	Belgium
4	Mikrosistemi Ltd	**µS**	SME; End-User	Bulgaria
5	Universität Bayreuth	**UBT**	HER	Germany
6	Technische Universiteit Delft	**TUD**	HER	Netherlands
7	Spanish National Research Council	**CSIC**	RES	Spain
8	IBM Research GmbH	**IBM**	IND; End-user	Switzerland
9	École polytechnique fédérale de Lausanne	**EPFL**	HER	Switzerland
10	SwissLitho AG	**SL**	SME; End-User	Switzerland
11	Oxford Instruments Nanotechnology Tools Ltd	**OINT**	IND; End-user	UK
12	Imperial College London	**IMPERIAL**	HER	UK
13	The Open University	**OU**	HER	UK
14	Oxford Scientific Consultants Ltd	**OSC**	SME	UK
15	VSL Dutch Metrology Institute	**VSL**	IND	Netherlands
16	University of Liverpool	**ULIV**	HER	UK

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<tr><td colspan="6">SNM
Work Package 12
Deliverable: D12.4 (“SNM slide presentation for publication & EC public presentation”)</td></tr>
<tr><td>Lead beneficiary number</td><td>1</td><td>Nature</td><td>R</td><td>Dissemination level</td><td>PU</td></tr>
<tr><td>Estimated Person-months</td><td colspan="5">0.4</td></tr>
<tr><td>Person-months by partner for the Deliverable</td><td colspan="5">TUIL
0.4</td></tr>
<tr><td>Estimated Delivery Date</td><td>04/2013</td><td colspan="2">Delivery Date</td><td colspan="2">06/2013</td></tr>
<tr><td>Description of the Deliverable</td><td colspan="5">• Presentation: see attachment</td></tr>
<tr><td>Explanation of Differences between Estimation and Realisation</td><td colspan="5">Delay in hiring coordination assistant (He started coordination work on 01.July 2013).</td></tr>
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" Single Nanometer Manufacturing for beyond CMOS devices "
SNM, GA No: 318804

Single Nanometer Manufacturing for beyond CMOS devices (SNM)

Large-scale integrating project (IP)
Work Program :
Challenge 3: Alternative Paths to Components and Systems
ICT 2011.3.1 Very advanced nanoelectronic components: design, engineering, technology and manufacturability

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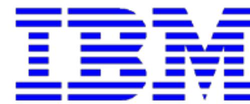
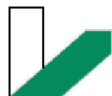
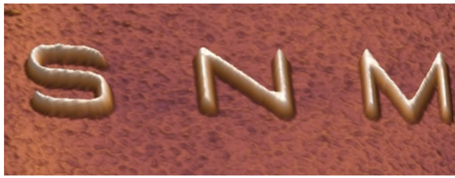
Project Consortium:



Dutch Metrology Institute

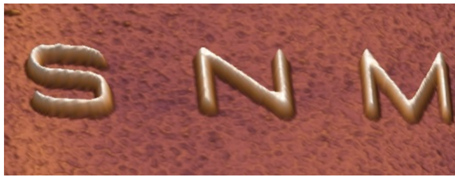




" Single Nanometer Manufacturing for beyond CMOS devices "

Project Consortium

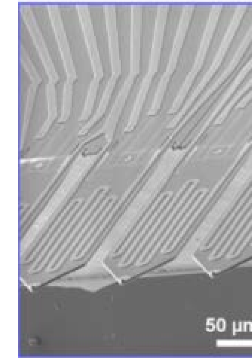
Part. Number	Partner	Partner	Country
1	TUIL	TECHNISCHE UNIVERSITÄT ILMENAU	Germany
2	EVG	EV GROUP E. THALLNER GMBH	Austria
3	IMEC	INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM VZW	Belgium
4	µS	MIRCOSYTEMS LTD	Bulgaria
5	UBT	UNIVERSITÄT BAYREUTH	Germany
6	TUD	TECHNISCHE UNIVERSITEIT DELFT	Netherlands
7	CSIC	AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS	Spain
8	IBM	IBM RESEARCH GMBH	Switzerland
9	EPFL	ECOLE POLYTECHNIQUE FEDERAL LAUSANNE	Switzerland
10	SL	SWISSLITHO AG	Switzerland
11	OINT	OXFORD INSTRUMENTS NANOTECHNOLOGY TOOLS LIMITED	United Kingdom
12	Imperial	IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE	United Kingdom
13	OU	THE OPEN UNIVERSITY	United Kingdom
14	OSC	OXFORD SCIENTIFIC CONSULTANTS LTD	United Kingdom
15	VSL	VSL B.V.	Netherlands

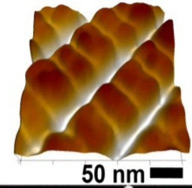


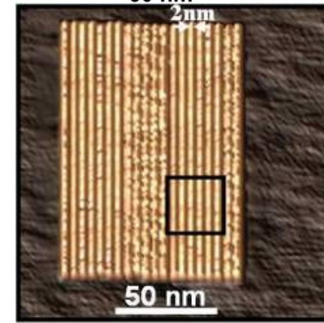
" Single Nanometer Manufacturing for beyond CMOS devices "

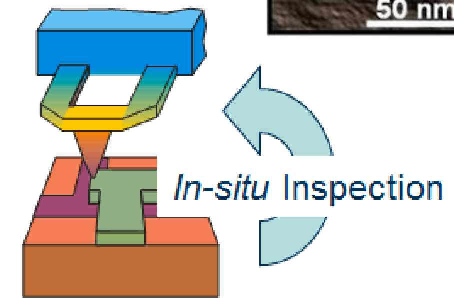
Project Targets

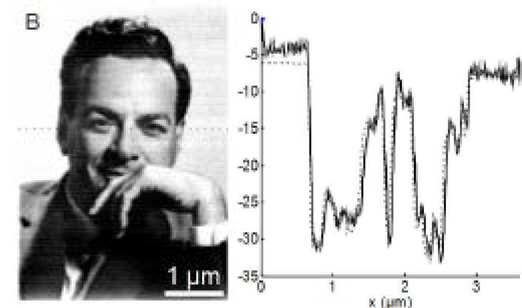
- **Prototype Single Nanometer Manufacturing Technology for Industry-oriented Applications using:**
- **Nanoresist material and Electron Beam Induced Deposition precursors**
- **Integrated process flow for Fabricating Nano-Imprint Templates, end-of-roadmap CMOS and beyond CMOS devices**
- **Demonstration of Overlay Alignment Concept with ultimately Accuracy at a Nano-Imprint Lithography Production System**
- **Development and Investigation of Manufacturable 'beyond CMOS' Devices**
- **Establishment of Metrology Specifications for 'beyond CMOS' Devices**

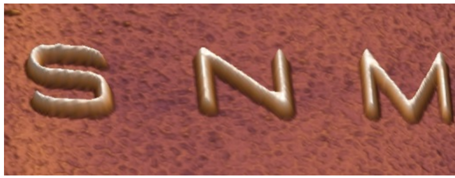










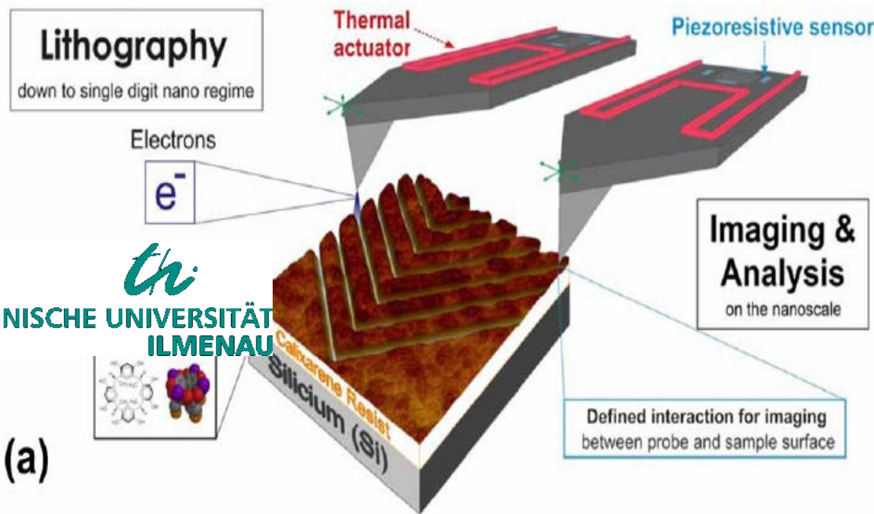


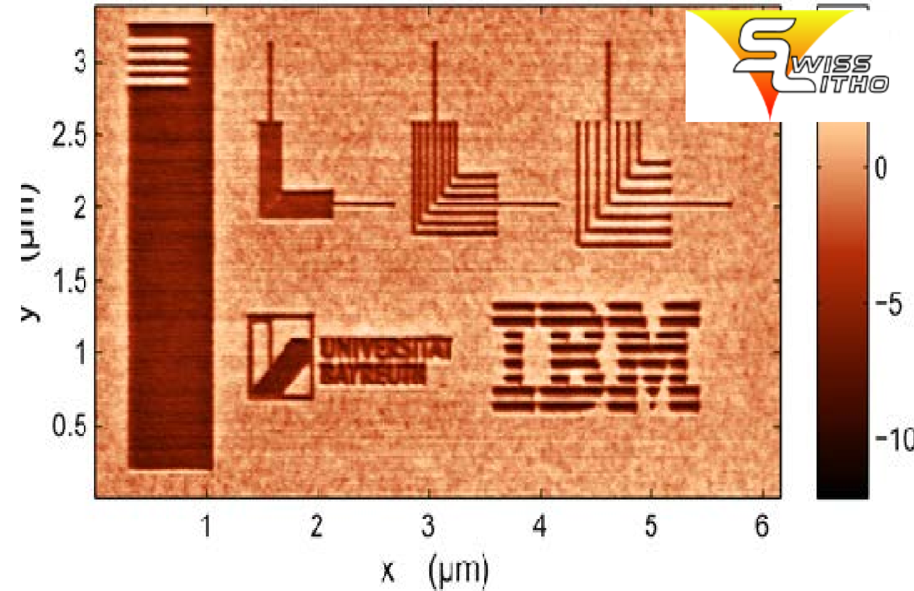
" Single Nanometer Manufacturing for beyond CMOS devices "

Tip-based Techniques for Single Nanometer Manufacturing

a) FN-field emission

a) Thermal tip





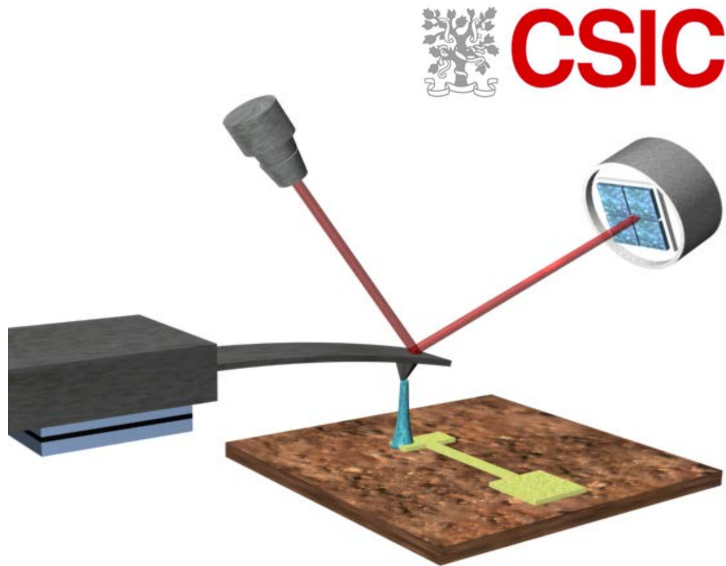
WPG1: Single Nanometer Lithography

Involved SNM partners: TUIL,EVG, μS,TUD,CSIC,IBM,SL,OSC

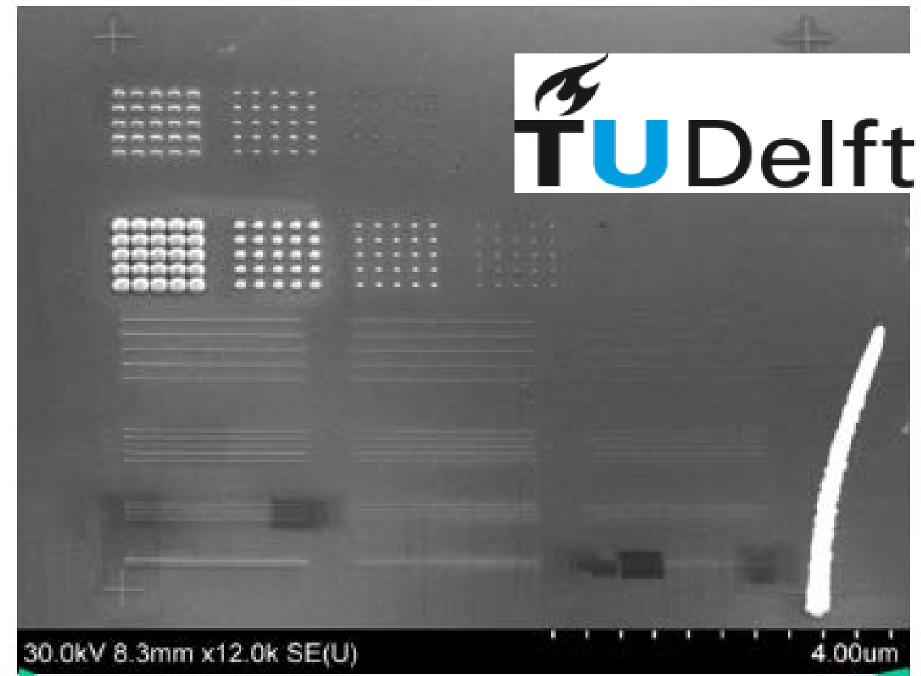
" Single Nanometer Manufacturing for beyond CMOS devices "

Deposition and Lithography Techniques for Single Nanometer Manufacturing

c) Tip-induced nanochemistry



d) Electron beam induced deposition lithography

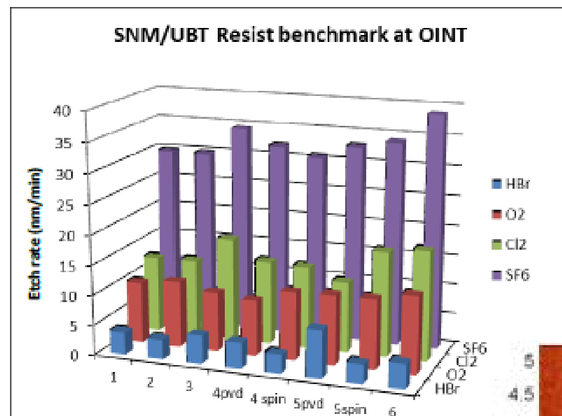


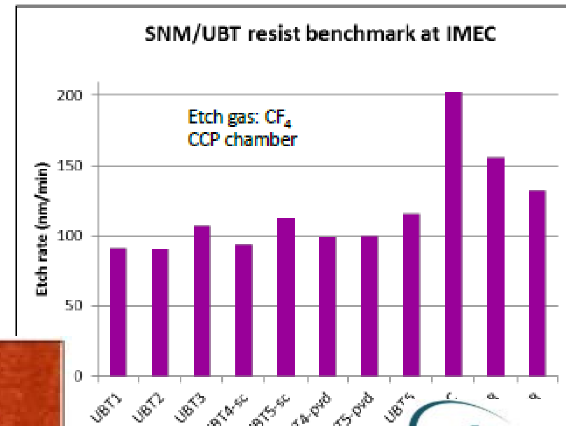
WPG1: Single Nanometer Lithography

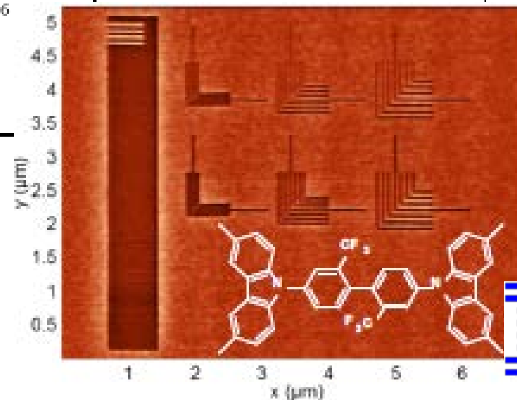
Involved SNM partners: TUIL,EVG, µS,TUD,CSIC,IBM,SL,OSC

" Single Nanometer Manufacturing for beyond CMOS devices "

Development and Investigation of New Resist Materials suitable for Etching and Tip-based Patterning







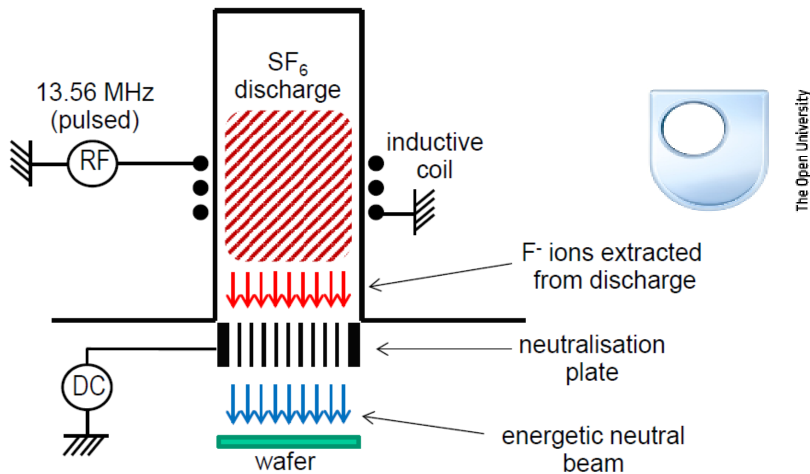
WPG2: Nano-Pattern-Transfer

Involved SNM partners: TUIL,IMEC,UBT,CSIC,IBM,EPFL,OINT,OSC,VSL

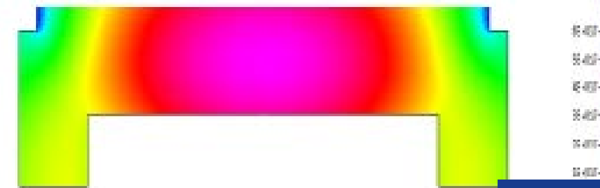
" Single Nanometer Manufacturing for beyond CMOS devices "

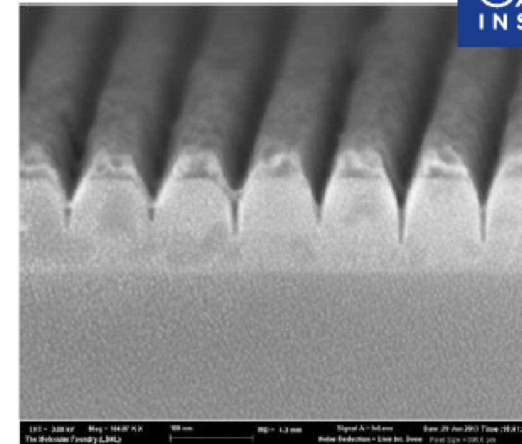
Nano-Pattern Transfer Techniques

a) Neutrals beam etching



b) Reactive ion etching
(Simulation and Experiments)





WPG2: Nano-Pattern-Transfer

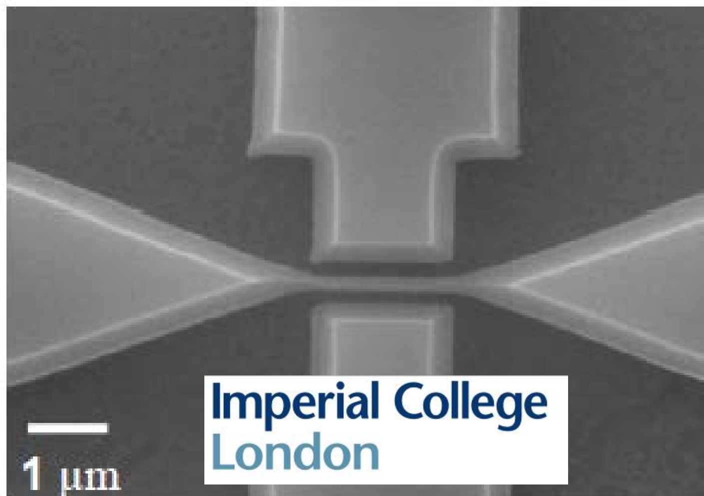
Involved SNM partners: TUIL,IMEC,UBT,CSIC,IBM,EPFL,OINT,OSC,VSL

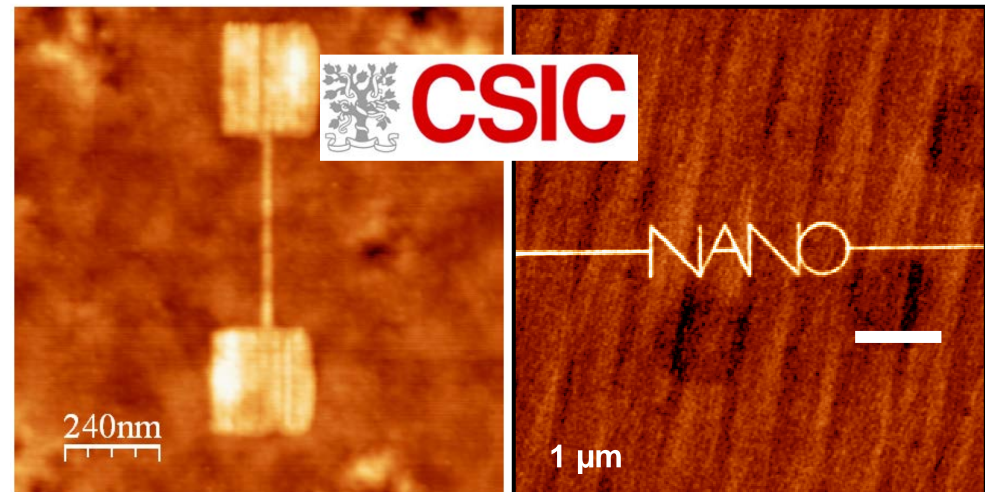
" Single Nanometer Manufacturing for beyond CMOS devices "

Beyond CMOS Nano-Devices based on different materials

a) Silicon Nanowire
Single Electron Transistors

b) Titanium Nanowires transistors





WPG3: Beyond CMOS

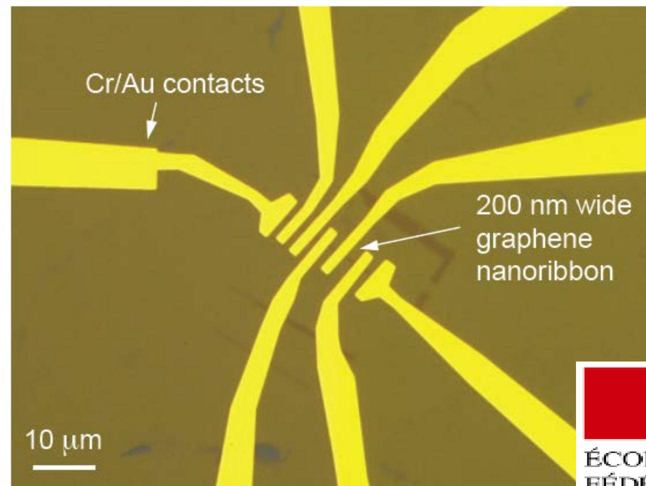
Involved SNM partners: TUIL,CSIC,IBM,EPFL,Imperial

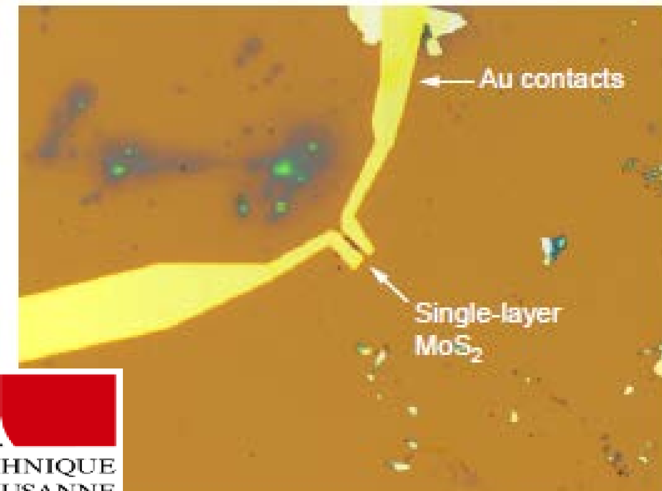
" Single Nanometer Manufacturing for beyond CMOS devices "

Beyond CMOS Nano-Devices based on different novel 2D materials

c) Graphene nanoribbon Field Effect Transistors

d) Molybdenum Disulfid Field Effect Transistors





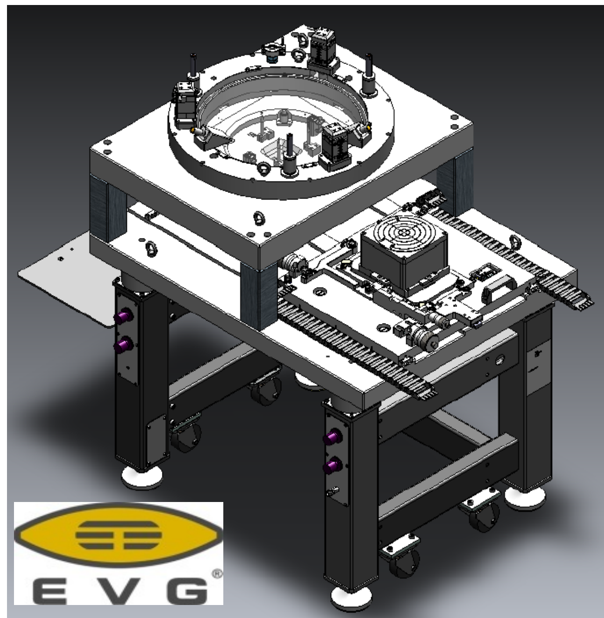
WPG3: Beyond CMOS

Involved SNM partners: TUIL,CSIC,IBM,EPFL,Imperial

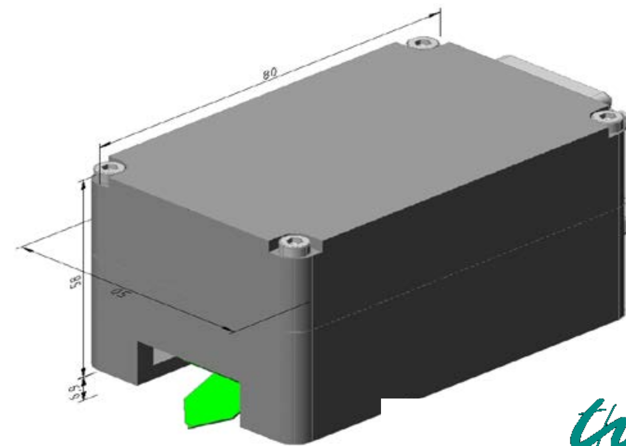
" Single Nanometer Manufacturing for beyond CMOS devices "

Single Nanometer Manufacturing Nano-Imprint System using Scanning Probe Microscopes for Overlay Alignment

a) Nano-Imprint System Layout



b) Specially designed and optimized "mouse-AFM"



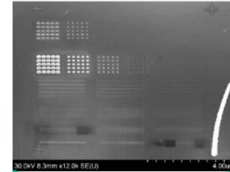
WPG4: High-Throughput Single-Nanometer Manufacturing

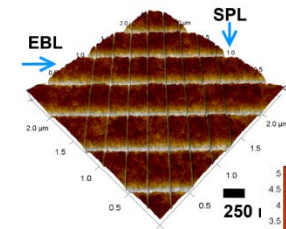
Involved SNM partners: TUIL,EVG,IMEC,µS,UBT,TUD,CSIC,IBM,SL,OINT,Imperial,VSL

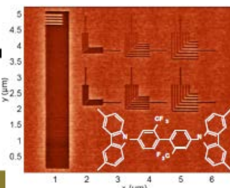
" Single Nanometer Manufacturing for beyond CMOS devices "

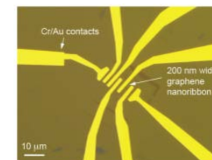
Important Achievements after Six Project Months

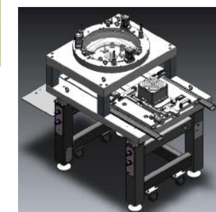
- Single Nanometer Structures fabricated with EBIDL
- Parallel Oxidation Lithography Device Prototype
- Complex 3D Pattern with 1nm vertical Accuracy
- Mix and Match Lithography for high Throughput combining EBL and SPL
- High Plasma Durability Molecular Glass Resists for tip-based Patterning and Pattern Transfer
- First preliminary "beyond CMOS" Devices realized
- Basic Concept of Scanning Probe Alignment Step-and-Repeat System.

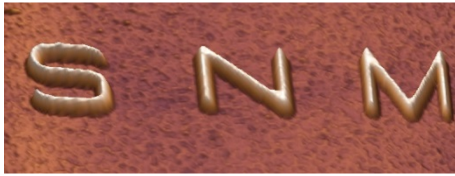












" Single Nanometer Manufacturing for beyond CMOS devices "

Dissemination

- **“International Society for Optics and Photonics“ SPIE Newsroom**:
  Scanning probe lithography for electronics at the 5nm scale, Z. Durrani, M. Kaestner, M. Hofer, Tzv. Ivanov and I.W. Rangelow

- **Mix & Match Electron Beam and Scanning Probe Lithography for sub-5 nm Pattering,** M. Kaestner, M. Hofer and I.W. Rangelow, *The 57th International Conference on Electron, Ion and Photon beam Technology & Nanofabrication Gaylord Opryland Resort Nashville, TN May 28 - May 31, 2013*

- **Scanning probe lithography for electronics at the 5nm scale,** Z. Durrani, M. Kaestner, M. Hofer, Tzv. Ivanov and I.W. Rangelow, ***SPIE 2013*** *Advanced Lithography 24-28 February 2013*

- **Scanning Probe Lithography approach for beyond CMOS devices,** Z. Durrani, M. Jones, M. Kaestner, M. Hofer, E. Guliyev, A. Ahmad, Tzv. Ivanov, J.-P. Zoellner and I.W. Rangelow
  Advanced Lithography, Proc. SPIE - Int. Soc. Opt. Eng. 2013, submitted

- **0.1-nanometer resolution positioning stage for sub-10nm scanning probe lithography,** N. Vorbringer-Doroshovets, F. Balzer, E. Manske, M. Kaestner, A. Schuh, J.-P. Zoellner, M. Hofer, E. Guliyev, A. Ahmad, Tzv. Ivanov and I.W. Rangelow, *Advanced Lithography, Proc. SPIE - Int. Soc. Opt. Eng. 2013, submitted*

- **Mix & Match Electron Beam & Scanning Probe Lithography for high troughput sub-10nm Lithography,** M. Kaestner, M. Hofer and I.W. Rangelow, *Advanced Lithography, Proc. SPIE - Int. Soc. Opt. Eng. 2013, submitted*

- **Nanolithography by scanning probes on calixarene molecular glass resist using Mix & Match lithography,** M. Kaestner, M. Hofer and I.W. Rangelow, *Invited Special Section Paper, JM3 (Journal of Micro/Nanolithography, MEMS and MOEMS, h5-index: 15) submitted*

- 11 Abstacts at MNE 2013 (incl. 1 invited)

- 1 Abstract at MRS 2013

We thank you for your attention!

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