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Annual report 2014

FOM programme nr. i16
'Innovative physics for oil and gas'

Foundation for Fundamental Research on Matter
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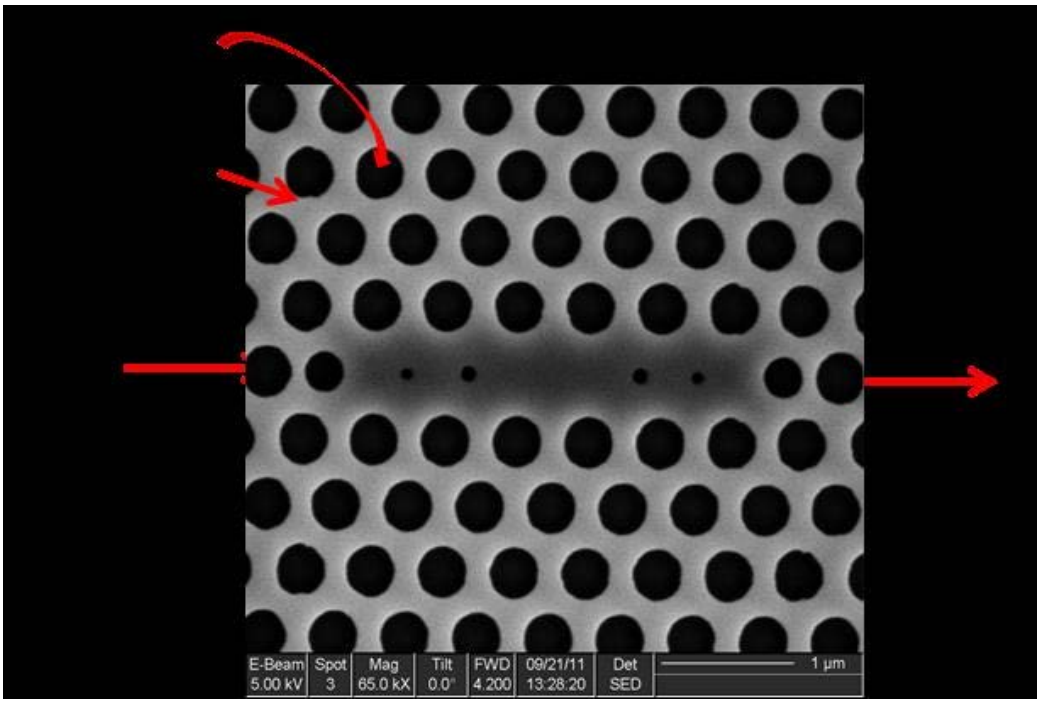

Nanophotonic sensors developed in this programme allow accurate discrimination between real reservoir oil types.

May 2015

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1. Scientific results 2014

This IPP will end in 2015, with six projects having ended in 2014 according to plan.

Below I summarize the main highights and results obtained in 2014.

The PhD project of O. Enriquez Paz y Puente in the group of Prosperetti, concerning enhanced growth of interacting bubbles, was successfully ended. During the project, detailed experimental investigations revealed how gas bubbles, trapped at a solid interface, grow and interact; such gas bubbles are abundantly present in oil reservoirs and understanding their growth is fundamental for enhanced oil recovery (EOR).

One of the major challenges in oil recovery is to locate and control the behavior of oil-water interfaces. Two separate projects in the group of Sprik and Bonn have been finished in 2014. In the thesis work of Dominik Michler, experiments were conducted to unravel the transport mechanisms of bubbles and vesicles in the presence of salt and surfactants in a constrictive environment, which revealed the conditions of transport towards or from the interface. In the postdoc project of Dr. Christiaan Schoemaker, the potential of the use of RFID's in oil exploration has been investigated (Dr. Christiaan Schoemaker). Simulations and measurements demonstrated that the RFID tags with dipole like antennas sense the dielectric environment and also the presence of conducting walls.

Based on existing concepts of silicon photonic cavities, optimized nano-photonic sensor for the detection of relevant parameters in enhanced oil recovery have been designed, fabricated and measured experimentally for spectral response to air, water and several reservoir oils in the group of Salemink. A further improved design and result has been obtained with small nanometer sized slots in the cavity to enhance the E-field sensitivity in and above the cavity. From the resulting experimental response spectra, it is now possible to discriminate between three real reservoir oil types. The iPOG project in 2014 and will now continue for an additional two years funded by Shell.

In the joint projects in the groups of Harting, Luding and Steeb, two projects are carried out to study ferromagnetic particles for EOR, and whether pulsed electromagnetic fields could be used to drive these particles to preferred regions. In 2014 the numerical part of this project ended succesfully with the PhD of S.C.J. Frijters, who studied in his thesis the magnetic interactions of particles at oil water interfaces. The experimental PhD work on I. Güven is ongoing, and a collaboration with the group of Daniel Bonn/Rudolf Sprik at the University of Amsterdamon the subject of stationary and dynamic streaming potential measurements including seismoelectric measurements is ongoing.

The PhD project of C Glass in the group of van Ruitenbeek on the development of piezoelectric nanoparticles for the imaging of oil reserves finished succesfully in 2014. In this project, vertically aligned piezoelectric zinc oxide nanorods were synthesised, as well as PZT nanorods. It is now possible to tune the aspect ratio and yield of ZnO nanorods by controlling the reaction conditions The piezoelectric properties of the PZT and ZnO nanorods that have been grow vertically on asubstrate were investigated via Piezoelectric Force Microscopy (PFM). Finally, first steps where taken in the engineering of nanorods for alignment in fluid flow, and the remote detection of electric signals due to acoustic excitation of piezoelectric nanorods.

In the PhD project of N Elbers in the group of Van Blaaderen, smart permeable nanoparticles are developed that attach to an oil-water interface and which can act as 'smart containers' for chemi-

cals like (liquid) surfactants. The particles made in this project can now be detached from the interface by addition of salt only (whereas other particles would stick to the surface). Experimental studies were performed on the microscopic interfaces formed by emulsion droplets, which give more insight into this process, which can be used to steer the smart particles. This project is well on schedule to finish in 2015, as planned.

2. Added value of the programme

An important goal of the programme is for Shell to initiate fundamental research with an application horizon in either seismic exploration (iPOG I) or nanoscience (iPOG II), to create greater awareness of the sort of scientific problems that are of interest to Shell, and to create better awareness of existing expertise within the academic physics community at Shell. This is a process that needs time, and some experimentation to find the optimal form, and this IPP programme has already played a crucial role in bringing these two communities closer together. I'm personally very happy that one of the successful projects has received now two additional years of funding from Shell, clearly showing the added value of this research.

3. Personnel

All of the positions have been filled, and in 2014 four PhD students graduated, and two postdoc projects ended; the remaining five PhDs and one postdoc are on track, and will finish their projects in 2015.

4. Valorisation and outreach

The project of postdoc Yazhao Liu in the group of Salemink, in which nanophotonic sensors are developed, had reached the stage of convincing proof of principle of an all-optical, nano-photonic sensor for the detection of relevant parameters in enhanced oil recovery in 2014, when the original postdoc contract of dr Liu ended. Shell has now funded a two year follow up project in which Dr. Liu and Salemink, in close collaboration with Shell, will further develop these sensors.

5. Vacancies

None.

FOM - 07.1529/10
datum: 01-01-2015

APPROVED INDUSTRIAL PARTNERSHIP PROGRAMME

Number	i16.
Title (code)	Innovative physics for oil and gas (iPOG)
Executive organisational unit	BUW
Programme management	Prof.dr. M.L. van Hecke
Duration	2008-2015
Cost estimate	M€ 4.5
Partner(s)	Shell

Concise programme description

a. Objectives

The general aim of this Industrial Partnership Programme (IPP) is to promote innovative basic research with potential relevance for the exploration and production of oil and gas reservoirs. The programme will have two open rounds. The research theme of the first round is 'Novel physical techniques to probe structure and transport in granular or heterogeneous media' and has a budget of M€ 2.0. The research theme of the second round is 'Novel physics for sensing modifying and manipulation of oil-gas reservoirs; a deep dive into the nano domain'. The budget for the second round, is ca. M€ 2.5.

b. Background, relevance and implementation

The detection and recovery of fossil-fuel reserves is complicated by the fact that the repertoire of methods to probe such reserves is limited. Direct drilling experiments are expensive and necessarily provide 'local' information. Imaging experiments provide information that is, at best, indirect. These problems are compounded by the fact that, as fossil fuel reserves diminish, exploration increasingly focuses on fields that are difficult to access. This makes it even harder to arrive at reliable assessments of the recoverable reserves. Straightforward optimization of existing exploration methods is yielding diminishing returns. For this reason, it becomes very interesting to look at original, even speculative, physical concepts that might be used to probe subterranean fossil fuel reserves. In addition, there is a great need to use novel computational techniques to arrive at optimal predictions concerning the recoverability of reserves, based on imaging probe data that are necessarily incomplete.
Moreover, recovery of hydrocarbons from the reservoir formation is far from optimal, with an estimated 40-60% of hydrocarbons being left behind in the porous and fractured network of a reservoir. As oil and gas field production matures over time, the recovery factor decreases even further and the production of unwanted saline formation water increases. So-called enhanced oil recovery (EOR) techniques have been developed and have been partly successfully applied to certain fields over the last decades to increase the production by a few percentages. However, these methods remain inefficient and expensive. Billions of barrels of unproduced hydrocarbons remain residually trapped in the pore space of the reservoirs.
To address these issues, Shell and FOM have initiated a joint Industrial Partnership Programme (IPP) to facilitate the exchange between academia and industry of relevant new ideas and to initiate pilot research programmes that aim to explore novel, physics-based methods to probe complex media , to

develop novel new chemo-physical concepts and materials to extract residually trapped hydrocarbon and to develop novel modeling techniques to analyze the resulting data.
The scientific programme of the first round of this IPP will bring together projects that:
(i) Probe fundamental aspects of acoustic waves in granular or heterogeneous media, in particular in the strongly scattering and nonlinear regime or where the waves couple to electro-kinetic transport.
(ii) Develop effective theory and model systems to capture these aspects of seismic waves.
Shell has a leading position in the use of seismic techniques for oil and gas recovery, but the present day techniques may no longer be sufficient to uncover and assess the reserves in the class of fields that presently are being targeted for production.

The scientific programme of the second round will bring together projects that:
(i) Develop novel nanophysical approaches for sensing, modifying and manipulation of (transport in) oil-gas reservoirs.
(ii) Develop effective theory and model systems to capture these aspects of the flow and activity of (nano)particles.

Truly innovative approaches, in which fundamental physics can play a key role, form the basis of iPOG. It should be stressed that since an important goal of this IPP is to extend the range of methods available, exploratory research is encouraged, and the programme is organized 'bottom-up', i.e. with an open call for proposals.

Funding
salarispeil cao per 01-07-2012

bedragen in k€	≤ 2014	2015	2016	2017	2018	2019	≥ 2020	Totaal
FOM-basisexploitatie	2.000	-	-	-	-	-	-	2.000
FOM-basisinvesteringen	-	-	-	-	-	-	-	-
Doelsubsidies NWO	-	-	-	-	-	-	-	-
Doelsubsidies derden	2.533	-	-	-	-	-	-	2.533
Totaal	4.533	-	-	-	-	-	-	4.533

The total contribution from Shell is M€ 2.5.

Source documents and progress control
a) Original programme proposal: FOM-07.1330
b) Ex ante evaluation: -
c) Decision Executive Board: FOM-07.1527
d) Contract: FOM-07.1424, FOM-05.0508/9

The programme leader is responsible for the progress of the programme and the knowledge transfer between the academic researchers and Shell researchers by means of annual meetings and semi-annual progress reports. The Steering Committee has to authorize the granting of proposals. Furthermore she has to authorize the research theme of the new rounds, before the budget of the new round can be unlocked. The first round started in 2008 and the second round started in 2009.

Remarks
The final evaluation of every round will be based on a self-evaluation report initiated by the programme leader at the end of that round.

MJ par. HOZB

Subgebieden : 50% NANO, 25% FeF, 25% COMOP

Historical overview of input en output

Input	personnel (in fte)				finances* (in k€)
	WP/V	WP/T	PhD	NWP	
2008	-	-	0.1	-	59
2009	-	0.4	1.6	-	191
2010	-	2.8	6.5	0.5	555
2011	-	4.8	9.0	0.3	782
2012	-	3.9	9.9	1.0	1,043
2013	-	2.4	9.7	0.3	762
2014	-	1.2	6.5	-	654

Output	PhD theses	refereed publications	other publications & presentations	patents
2012	-	9	27	-
2013	-	20	47	-
2014	3	19	41	-

* After closing the financial year.

PhD defences

2012
None.
2014
Rojman Zargar, 5 December 2014, FOM-A-03.
Stefan C.J. Frijters
Christian Glass

2013
J. Aulbach, 20 September 2013, AMOLF.

Patents (new/changes)

2013
None.

2014
None.

Overview of projects and personnel

Workgroup FOM-A-03

Leader	Prof.dr. D. Bonn
Organisation	University of Amsterdam
Programme	Innovative physics for oil and gas
Project (title + number)	Soft modes in wet granular systems 08iPOG04

FOM employees on this project

Name	Position	Start date	End date
R. Zargar	PhD	13 October 2009	12 January 2014

Workgroup FOM-A-07

Leader	Dr. R. Sprik
Organisation	University of Amsterdam
Programme	Innovative physics for oil and gas
Project (title + number)	Using 'smart dust' in oil recovery 09iPOG03

FOM employees on this project

Name	Position	Start date	End date
F.C. Schoemaker	postdoc	01 January 2012	15 April 2014
D. Michler	PhD	15 October 2010	14 October 2014

Leader	Dr. R. Sprik
Organisation	University of Amsterdam
Programme	Innovative physics for oil and gas
Project (title + number)	Correlation imaging with seismo-electromagnetic waves 08iPOG05-1

FOM employees on this project

Name	Position	Start date	End date
S. Nakhaee	PhD	17 May 2010	16 May 2015

Workgroup FOM-D-39

Leader	Prof.dr.ir. C.P.A. Wapenaar
Organisation	Delft University of Technology
Project leader	Prof.dr.ir. E.C. Slob
Programme	Innovative physics for oil and gas
Project (title + number)	Correlation imaging with seismo-electromagnetic waves 08iPOG05-2

FOM employees on this project

Name	Position	Start date	End date
N. Grobbe	PhD	01 September 2010	31 August 2015

Workgroup FOM-E-21

Leader	Prof.dr. A.A. Darhuber
Organisation	Eindhoven University of Technology
Project leader	Dr. J.D.R. Harting
Programme	Innovative physics for oil and gas
Project (title + number)	Detection and guidance of nanoparticles for enhanced oil recovery 09iPOG14-1

FOM employees on this project

Name	Position	Start date	End date
S.C.J. Frijters	oio	18-1-2010	15-3-2014

Workgroup FOM-L-22

Leader	Prof.dr. J.M. van Ruitenbeek
Organisation	Leiden University
Programme	Innovative physics for oil and gas
Project (title + number)	Ferroelectric nanoparticles for imaging of oil reserves 09iPOG16

FOM employees on this project

Name	Position	Start date	End date
C. Glass	PhD	01 May 2010	31 October 2014

Workgroup FOM-N-25

Leader	Prof.dr. H.W.M. Salemink
Organisation	Radboud University Nijmegen
Programme	Innovative physics for oil and gas
Project (title + number)	NanoPhotonicSensors (NPS) 09iPOG09

FOM employees on this project

Name	Position	Start date	End date
Y. Liu	postdoc	1-6-2012	28-11-2014

Workgroup FOM-T-03

Leader	Prof.dr. D. Lohse
Organisation	Twente University
Project leader	Prof.dr. A. Prosperetti
Programme	Innovative physics for oil and gas
Project (title + number)	Enhanced growth of interfacing bubbles 09iPOG01

FOM employees on this project

Name	Position	Start date	End date
O.R. Enriquez Paz y Puente	PhD	15 October 2010	13 January 2015

Workgroup FOM-T-28

Leader	Prof.dr. S. Luding
Organisation	Twente University
Project leader	Prof. dr. H. Steeb (Ruhr University Bochum))
Programme	Innovative physics for oil and gas
Project (title + number)	Detection and guidance of nanoparticles for enhanced oil recovery 09iPOG14-2

FOM employees on this project

Name	Position	Start date	End date
I. Güven	postdoc	01 January 2012	31 December 2015

Workgroup FOM-U-09

Leader	Prof.dr. A. van Blaaderen
Organisation	Utrecht University
Programme	Innovative physics for oil and gas
Project (title + number)	Smart nanoparticles at the oil-water interface for EOR 09iPOG17

FOM employees on this project

Name	Position	Start date	End date
N.A. Elbers	PhD	01 October 2010	7 August 2015