FOM - 15.0324

Annual report 2014

FOM programme nr. i34
'Fundamental fluid dynamics challenges of extreme ultraviolet lithography

Foundation for Fundamental Research on Matter
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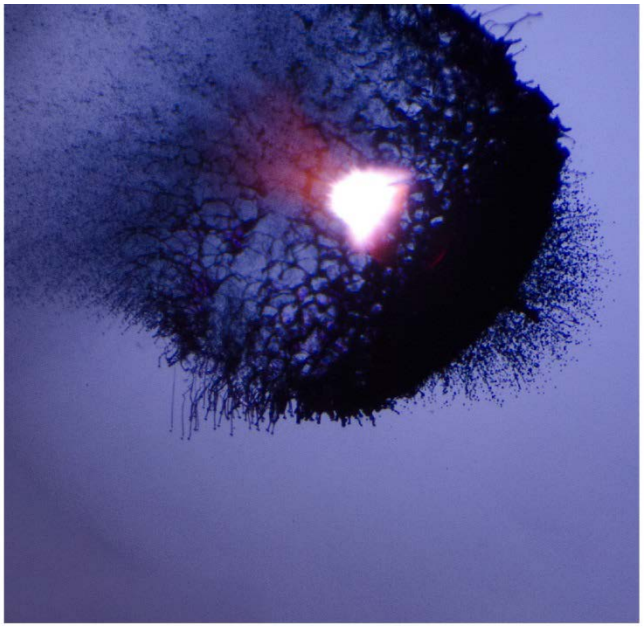

Explosion of a dyed water drop following the impact of a 10-nanosecond laser pulse.

May 2015

Content

1. Scientific results 2014

We have a fully equipped operational lab at ASML since the end of July 2014. First experiments showing the violent response of a liquid drop to laser impact have been successfully performed in the lab in Twente. A detailed analysis and quantitative understanding of the drop propulsion mechanism and deformation following laser impact have been acquired, based on a combination of beautiful experimental movies, quantitative experimental data and analytical and numerical modelling. These results have led to the Milton van Dyke prize at the APS-DFD Gallery of Fluid Motion 2014 and two forthcoming publications (to appear in 2015). A further optimized version of the experimental set-up, which allows for a more detailed study of the drop fragmentation following laser impact, has now been realised at the ASML site. The first quantitative results with this new set-up are expected in the course of 2015. In collaboration with Federico Toschi (TU/e) a Lattice Boltzmann model to study laser-impact on a drop has been set up. This project was part of a MSc thesis work that will be continued as a PhD project in 2015.

An exploratory study on the use of soft substrate materials to control the splashing and deposition of a liquid drop upon impact has been performed. In collaboration with the University of Wageningen hydrogels with controllable (visco-) elasticity have been selected and first impact experiments on hydrogels with different elastic properties have been performed to explore the different impact regimes. Furthermore, the splashing threshold for drops impacting on an elastic membrane covering a liquid pool has been quantified. The dependence of this threshold on the drop (size, impact speed) as well as the membrane properties have been studied both experimentally and theoretically. In addition, some first impact experiments with liquid metal drops have been performed to study the role of drop solidification and possibly oxidation during impact. In January 2015 a postdoc fully focussing on drop solidification during deposition and impact will join the project. We expect the first quantitative results in 2015.

2. Added value of the programme

The fact that we spend most of the time on the ASML premises, with our set-ups in a lab shared with ASML researchers, ensures a much closer collaboration than what would have been possible in an IPP performed entirely in the university context. It took some time for both our team and ASML to get used to our presence there, since both the FOM and ASML researchers need(ed) to learn what to expect from each other and how to use each others knowledge in the optimal way. Currently things are running much smoother; we frequently discuss with researchers from ASML to exchange knowledge, and get new ideas for our existing and possible new fundamental projects inspired by the engineering challenges researchers at ASML are facing.

As part of the laser-drop project, we have a very fruitful collaboration with E. Villermaux (Aix-Marseille University) and H. Lhuissier (ESPCI Paris). In addition, we have started a collaboration with F. Toschi (TU/e) on the numerical modelling of laser impact on a drop with the Lattice Boltzmann method. In 2015, we are starting a collaboration with W. Ubachs and R. Hoekstra (ARCNL) to study the details of laser impact on liquid metal drops. For the drop impact project, we collaborate with J. Sprakel (Wageningen University), expert on hydrogels and microrheology.

3. Personnel

Two PhD positions and the groupleader position have been filled since 2013. The third (and last) PhD position of the programme will be filled in March 2015 by S.A. Reijers. In addition, we have had one MSc student (S.A. Reijers) and one intern (Y. Zhao) working on the project in 2014. A postdoc (Riëlle de Ruijter) funded by TKI money has been appointed in January 2015. In the first half of 2014, quite some time was spent on organisational aspects and getting started at ASML,

mainly in arranging suitable lab space and equipment. After this initial delay, the two PhD students working on the project in 2014 (A.L. Klein and M.V. Gielen) are now both on track with their projects. In 2014 and the first half of 2015 M.V. Gielen spent/will spend quite some time on teaching, because she is following the 'Promovendi voor de klas' programme. She will get an extension of her PhD contract of 6 months to compensate as part of this programme.

The team has won three prizes this year: the Milton van Dyke award in the APS-DFD Gallery of Fluid motion 2014 by A.L. Klein et al., and the FOM Physics thesis Prize and Charles Hoogendoorn award by H. Gelderblom.

4. Publications

- A.L. Klein, W. Bouwhuis, C.W Visser, H. Lhuissier, C. Sun, J.H. Snoeijer, E. Villermaux, D. Lohse and H. Gelderblom, 'Laser impact on a drop', winning entry Gallery of Fluid Motion 2014, American Physical Society- Division of Fluid Dynamics, San Francisco 2014.

5. Valorisation and outreach

As discussed above, frequent exchange with ASML is inherent of our programme. Our input and results are used by ASML researchers on a regular basis.

Outreach activities:
- Invited talk H. Gelderblom at NWO Bessensap 2014: 'Van spetterende fysica tot snellere iPhone'.
- Popular science article in ScienceNews December 2014: 'Assaulting ink drops for science'.

6. Vacancies

All positions are filled from early 2015 on.

APPROVED INDUSTRIAL PARTNERSHIP PROGRAMME

Number	i34.
Title (code)	Fundamental fluid dynamics challenges of extreme ultraviolet lithography (FEUL)
Executive organisational unit	BUW
Programme management	Prof.dr. D. Lohse
Duration	2013 – 2018
Cost estimate	M€ 1,7
Partner(s)	ASML

Concise programme description

a. Objectives

Extreme Ultraviolet Lithography (EUVL) is considered to be the future technology for the production of Integrated Circuits, yet there are major fundamental and technological challenges to overcome. The objective of the project is:

- To achieve a better control of the debris formation to reduce contamination of the optical elements in the EUV machine, especially the source optics.
- To maximize the conversion efficiency from laser power to EUV by properly shaping the tin droplet.

b. Background, relevance and implementation

Major technological challenges at ASML have their origin in fundamental fluid dynamical problems. This in particular holds for some crucial phenomena in EUV sources for the next generation of lithography machines, on which the future of ASML depends.
The chosen strategy to cope with this problem is to set up a fundamental fluid dynamics group (one group leader and three PhD students) for ASML that will be located within the laboratories of ASML in Veldhoven, with a long-term perspective and a close link to Physics of Fluids groups at the universities within the Netherlands and abroad. This group should be problem-oriented and able to transfer the knowledge from the university groups to ASML and vice-versa make the university groups aware of the fundamental fluid dynamical challenges at ASML.

The focus of this IPP is on understanding and solving the fundamental fluid dynamical issues inside the EUV source by performing controlled experiments, high-speed visualization, numerical simulations, and theoretical modelling. These challenges directly touch upon contemporary research in fluid physics, pushing the boundaries into a barely explored range of parameters.

Funding
salarispeil cao tot 01-07-2012

bedragen in k€	≤ 2014	2015	2016	2017	2018	2019	≥ 2020	Totaal
FOM-basisexploitatie	248	-	-	-	-	-	-	248
FOM-basis investeringen	250	250	-	-	-	-	-	500
Doelsubsidies NWO	-	-	-	-	-	-	-	-
Doelsubsidies derden								
- ASML [1)]	250	195	195	268	65	-	-	973
Totaal	275	325	325	325	166	-	-	1.721

1) Bovenop de *in cash* bijdrage, draagt ASML circa k€ 600 *in kind* bij aan het programma voor huisvesting en gebruik van apparatuur, faciliteiten en diensten door de FOM-groep.

Source documents and progress control

a) Original programme proposal: FOM-13.0514
b) Ex ante evaluation: FOM-13.0931, FOM-13.0992
c) Decision Executive Board: FOM-13.1242
d) Contract: FOM-13.0125, FOM-13.1343

Remarks

For the programme a scientific advisory committee is established that meets yearly, and monitors progress of the programme. A supervisory board oversees overall progress of the programme. Drastic changes require approval of the supervisory board.
The final evaluation of this programme will consist of a self-evaluation initiated by the programme leader and is foreseen in 2018.

MH par. HOZB

Subgebied: 100% FeF

Historical overview of input en output

Input	personnel (in fte)				finances* (in k€)
	WP/V	WP/T	PhD	NWP	
2013	-	0.6	0.6	-	41
2014	-	1.0	2.0	-	383

Output	PhD theses	refereed publications	other publications & presentations	patents
2014	-	-	12	-

* After closing the financial year.

PhD defences

2014
None.

Patents (new/changes)

2014
None.

Overview of projects and personnel

Workgroup FOM-T-03

Leader	Prof.dr. D. Lohse
Organisation	University of Twente
Programme	Fundamental fluid dynamics challenges of extreme ultraviolet lithography
Project (title + number)	Groupleader (13FEUL01)

FOM employees on this project

Name	Position	Start date	End date
H. Gelderblom	WP/T	1 June 2013	31 May 2018

Leader	Prof.dr. D. Lohse
Organisation	University of Twente
Project leaders	Dr.ir. H. Gelderblom
Programme	Fundamental fluid dynamics challenges of extreme ultraviolet lithography
Project (title + number)	Tin droplet impact, shaping and fragmentation (13FEUL02)

FOM employees on this project

Name	Position	Start date	End date
M.V. Gielen	PhD	1 October 2013	30 September 2017
A.L. Klein	PhD	15 August 2013	14 August 2017