

Contents

1	Introduction	1
1.1	Motivation	1
1.2	Plasma-Based Electron Acceleration: A Historical Overview	2
1.3	The Present Electron Acceleration Work	6
1.4	Motivation for the Development of Microscopic de Laval Nozzles	7
1.5	Supersonic (Micro) Gas Jets	7
1.6	Structure of the Thesis	10
	References	11

Part I Supersonic Micro-Jets

2	Theory of Compressible Fluid Flow	21
2.1	One-Dimensional Theory of Compressible Fluid Flow	21
2.1.1	Equation of State and the First Principal Law	21
2.1.2	Changes of State	23
2.1.3	Compressible Gas Flow in 1D: Perturbations and Shocks	24
2.1.4	Continuous Flows in Nozzles	30
2.1.5	Cluster Formation in Supersonic Gas Jets	37
	References	39
3	Numeric Flow Simulation	41
3.1	Flow Models for Computational Fluid Dynamics	41
3.1.1	Parameterization of de Laval Nozzles	42
3.1.2	Size Effects and Effects of Low Pressure	43
3.1.3	Boundary Layers	45

3.2	Simulation Results	46
3.2.1	Supersonic Flows and the de Laval Nozzle	46
3.2.2	Optimal Nozzle Shape	50
3.2.3	Influence of the Nozzle Geometry on the Flow Parameters	51
3.2.4	Effects of Nozzle Size and Varying Backing Pressure	59
3.2.5	Effects of Non-Negligible Background Pressure	66
3.2.6	Gas Targets with Additional Degrees of Freedom	67
	References	70
4	Experimental Characterization of Gas Jets	71
4.1	Experimental Setup for Characterizing Gas Jets	71
4.2	Numerical Evaluation of Experimental Data	72
4.3	Experimental Results on Gas Jets	74
4.4	Shock Fronts in Supersonic Gas Jets	77
	References	78
 Part II Few-Cycle Laser-Driven Electron Acceleration		
5	Electron Acceleration by Few-Cycle Laser Pulses: Theory and Simulation	83
5.1	Introduction to Relativistic Laser-Plasma Physics	83
5.1.1	Non-Relativistic Cold Collisionless Plasmas	83
5.1.2	Relativistic Threshold Intensity	86
5.1.3	Relativistic Single Electron in EM Field	87
5.1.4	Relativistic Cold Collisionless Plasma Equations	89
5.1.5	Electromagnetic Waves: Self-Focusing	91
5.1.6	Electrostatic Waves: Wave Breaking	94
5.1.7	Laser Wakefield Acceleration and Scaling Laws	97
5.2	Results of Particle-In-Cell Simulations	102
	References	106
6	Experimental Setup	109
6.1	The Light Source: Light Wave Synthesizer 10	109
6.2	Setup of the Experiment	113
	References	116
7	Experimental Results on Electron Acceleration	119
7.1	Performance and Stability of the Electron Accelerator	119
7.2	Multiple Accelerated Electron Bunches	127
7.3	Discussion of the Experimental Results	128
	References	130

Contents	xiii
8 Next Steps for Optimizing the Accelerator	131
References	137
9 Conclusion.	141
References	143
Appendix A: Numeric Setup of the Fluid Flow Simulations	145
Appendix B: Nozzle Designs	155
Curriculum Vitae	163