FINAL REPORT

DOE Contract DE-AS03-83-ER40120

DOE/ER/40120--T3

"Experimental, Theoretical, and Computational Studies of the Plasma Beat Wave Accelerator Concept"

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Abstract

This is the final report on DOE contract no. DE-AS03-83-ER40120, "Experimental, Theoretical, and Computational Studies of the Plasma Beat Wave Accelerator Concept," P.I., Professor C. Joshi. As can be seen this was an extremely productive period with the PI and his team completing all the tasks in the original proposal.

Main Accomplishments

The following six pages list the work statement as it appeared in the initial proposal. Next to it is a summary of what the actual performance was. A check mark means the accomplishment was exactly as planned in the work statement. A list of key publications under each main subtask in the work statement are also listed.

TASK	PROPOSED GOAL	ACTUAL ACCOMPLISMENT
1) Beat Wave Acceleration in a Gas Jet December 1992	a) Characterize jet	✓
	b) Two-frequency illumination	✓
	c) Thomson scatter diagnostic of density	✓
	d) Thomson scatter diagnostic of accelerating wave	✓
	e) Stokes and anti-Stokes diagnostics	✓
	f) Harmonic emission from such a plasma	✓
	g) Electron injection & acceleration	✓
	h) Dipole magnet and cloud chamber measurements of accelerated electrons	Electron energy gain less than 1 MeV because of finite interaction length.

Work published:

C. E. Clayton and M. J. Everett, "Measurements of the Transverse and Longitudinal Density Profiles in a Pulsed Supersonic Nitrogen Gas Jet," submitted to Review of Scientific Instruments.

TASK	PROPOSED GOAL	ACTUAL ACCOMPLISMENT
2) Beat Wave Acceleration in Static Gas	a) Extend the beat wave interaction length up to 10 cm	Tunnel ionization in static gas used to produce uniform plasmas ~ 2 cm long
	b) Characterize plasmas	✓
until June 95	c) Thomson scatter diagnostic of density	✓
	d) Measure frequency wavenumber, time and spatial structure of the accelerating wave	All carried out successfully
	e) Inject and accelerate electrons	Electrons accelerated to 30 MeV. Both decelerated and accelerated electrons detected.

Work Published in Numerous Papers:

1. W. Leemans et al., "Stimulated Compton Scattering From Pre-formed Underdense Plasmas," Physical Review Letters 67, 1434 (1991).

2. W. Leemans et al., "Plasma Physics Aspects of Tunnel-Ionized Gases," Physical Review Letters 68, 321 (1992).

3. C. Clayton et al., "Ultrahigh Gradient Acceleration of Injected Electrons by Laser-Excited Relativistic Electron Plasma Waves, Physical Review Letters 70, 37 (1993).

4. M. Everett et al., "Demonstration of Trapped Electron Acceleration by a Laser-Driven Relativistic Plasma Wave, Nature 368, 527 (1994).

5. M. J. Everett, A. Lal, D. Gordon, K. Wharton, C. E. Clayton, W. B. Mori, and C. Joshi, "Evolution of Stimulated Raman into Stimulated Compton Scattering of Laser Light via Wave-Breaking of Plasma Waves," Physical Review Letters 74, 1355-1358 (February, 1995).

6. M. J. Everett, A. Lal, C. E. Clayton, W. B. Mori, and C. Joshi, "Coupling Between High-Frequency Plasma Waves in Laser-Plasma Interactions," Physical Review Letters 74, 2236-2240 (March, 1995).

TASK	PROPOSED GOAL	ACTUAL ACCOMPLISMENT
3) Short-Pulse Expts At LLNL	a) Characterize short pulse plasma	Both gas jet and static fill plasmas produced by short pulses characterized
Dec 1992 - April 1994	b) Carry out low density expts to look for wake fields	Wake fields not observed but strongly driven Raman seen
March 94 - Present	c) High density Raman forward expts look for hot electrons	Successfully carried out electrons up to 2 MeV seen. Expts also carried out at Rutherford. Electron acceleration up to 44 MeV observed.

Work published:

1. C. Darrow et al., "Strongly Coupled Stimulated Raman Backscatter From Sub-picosecond Laser-Plasma Interactions," Physical Review Letters 69, 442 (1992).

2. C. A. Coverdale, C. B. Darrow, C. D. Decker, W. B. Mori, K.C. Tzeng, K. A. Marsh, C. E. Clayton, and C. Joshi, "Propagation of Intense Subpicosecond Laser Pulses Through Underdense Plasmas, Physical Review Letters **74**, 4659-4662 (June, 1995).

3. A. Modena, Z. Najmudin, A. E. Dangor, C. E. Clayton, K. A. Marsh, C. Joshi, V. Malka, C. B .Darrow, C. Danson, D. Neely and F. N. Walsh, "Electron Acceleration from the Breaking of Relativistic Plasma Wave," Nature **377**, 606-608 (October, 1995).

4. C. Coverdale, C. B. Darrow, C. D. Decker, N. Naumova, S. Bulanov, W. B. Mori, K-C. Tzeng, "Temporal Bursting of Stimulated Raman Backscatter in an Underdense Plasma," submitted to Physical Review Letters, 1995.

5. K-C. Tzeng, W. B. Mori, C. D. Decker, "The Anomalous Absorption and Scattering of Short-Pulse High-Intensity Lasers in Underdense Plasmas," submitted to Physical Review Letters, 1995.

TASK	PROPOSED GOAL	ACTUAL ACCOMPLISMENT
4) Plan and propose the next phase of expts on plasma acceleration Dec 1992 - Present	Make a comparison of PBWA and self-modulated (RFS) approaches	A 1 GeV range PBWA expt proposed. Goal Modified to 100 MeV PBWA Expt but high quality electron beam

Work Published:

1. C. Joshi et al., "The Prospects for a GeV Plasma Beat Wave Accelerator," Comments on Plasma Physica and Controlled Fusion 16, 65 (1994).

See "Special Issue on 2nd Generation Plasma Accelerators," IEEE Trans. on Plasma Science, ed. by T. Katsouleas, Proceedings of the Kardamyli Workshop, June 26-30, 1995.

TASK	PROPOSED GOAL	ACTUAL ACCOMPLISMENT
5) 20 MeV Linac Development (with C. Pellegrini)	a) Phase lock the drive laser with rf	✓
	b) Parametric scaling of photo-injector output current with laser parameters	✓
	c) Design and build a second gun for PBWA applications	Being carried out with BNL & SLAC
	d) Participate in all aspects of the linac development to 20 MeV	10+ MeV at 3.5 nC demonstrated

Work Published:

1. R. Brogle, P. Muggli, P. Davis, G. Hairapetian, and C. Joshi, "Studies of Linear and Nonlinear Photoelectric Emission for Advanced Accelerator Applications," proceedings of the PAC Conference, Dallas, TX, May 1-5, 1995.

2. P. Davis, G. Hairapetian, M. Hogan, C. Joshi, M. Lampel, S. Park, C. Pellegrini, J. Rosenzweig, G. Travish and R. Zhang, "The UCLA Compact High Brightness Electron Accelerator," proceedings of the PAC Conference, Dallas, TX, May 1-5, 1995.

+ many other publications with C. Pellegrini's Group

TASK	PROPOSED GOAL	ACTUAL ACCOMPLISMENT
6) Plasma Lens	a) Install Gas Jet on 20 MeV linac	RF source used to produce low density plasma
	b) Produce very low density plasma via photoionization	4 MeV beam focused as dynamic nature of focusing diagnosed using a streak camera
	c) Try focusing electron beam and diagnose it	A test set-up for fundamental studies of photoemitting materials set up.

Work Published:

1. G. Hairapetian et al., "Experimental Demonstration of Dynamic Focusing of a Relativistic Electron Bunch by an Overdense Plasma Lens," Physical Review Letters 72, 2403 (1994).

2. G. Hairapetian, P. Davis, C. E. Clayton, C. Joshi, C. Pellegrini, and T. Katsouleas, "Transverse Dynamics of a Short, Relativistic Electron Bunch in a Plasma Lens," Physics of Plasmas 2, 2555-2561 (June, 1995).

3. G. Hairapetian, "Plasma Lenses," AIP Conference Proceedings No. 335, ed. by P. Schowssow.

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2. D. W. Forslund, J. M. Kindel, W. Mori, C. Joshi and J. M. Dawson, Physical Review Letters 54, 558 (1985).

3. C. E. Clayton, C. Joshi, C. Darrow and D. Umstadter, Physical Review Letters 54, 2343 (1985).

4. P. Chen et al, Physical Review Letters 54, 693 (1985).

5. C. Joshi, "Laser Accelerators," IEEE Transactions Nucl. Sci., October (1985).

6. C. Clayton, C. Joshi, C. Darrow, D. Umstadter, and F. F. Chen, IEEE Transactions Nucl. Sci., October (1985).

7. T. Katsouleas, J. M. Dawson, D. Sultana and Y. T. Yan, "A Side-Injected Laser Plasma Accelerator, " IEEE Trans. Nucl. Sci., October (1985).

8. W. B. Mori, C. Joshi, J. M. Dawson, K. Lee, D. Forslund, and J. Kindel,"Studies of the Plasma Droplet Accelerator Scheme," IEEE Trans. Nucl. Sci., October (1985).

9. D. W. Forslund, J. M. Kindel, W. Mori, C. Joshi, and J. M. Dawson, "Two Dimensional Simulations of Single Frequency and Beat Wave Laser-Plasma Heating," Physical Review Letters 54, 6:558-561 (1985).

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12. C. Darrow, D. Umstadter, T. Katsouleas, W. B. Mori, C. E. Clayton, and C. Joshi, "Saturation of Beat-Excited Plasma Waves by Electrostatic Mode Coupling," Physical Review Letters 56, 2629 (1986).

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16. C. Joshi, "Relativistic Plasma Waves and Particle Acceleration," Physics Today, January (1987).

17. W. B. Mori, "On Beat Wave Excitation of Relativistic Plasma Waves," IEEE Transactions on Plasma Science PS-15, 88 (1987).

18. S. Wilks, T. Katsouleas, J. M. Dawson, P. Chen, and J. J. Su, "Beam Loading in Plasma Waves, IEEE Trans. On Plasma Science, ed. By T. Katsouleas, April (1987).

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20. P. Chen, J. J. Su, T. Katsouleas, S. Wilks, and J. M. Dawson, "Plasma Focusing for High Energy Beams," IEEE Trans. On Plasma Science, ed. By T. Katsouleas, April (1987).

21. C. Joshi, T. Katsouleas, J. M. Dawson, Y. T. Yan, and J. M. Slater, "Plasma Wave Wigglers for Free Electron Lasers," IEEE J. of Quantum Electronics, QE-23, 1571 (1987).

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27. S. C. Wilks, J. M. Dawson, and W. B. Mori, "Frequency Up-Conversion of Electromagnetic Radiation with Use of an Overdense Plasma," Physical Review Letters 61, 337 (1988).

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40. W. B. Leemans, C. Joshi, W. B. Mori, C. E. Clayton, and T. W. Johnston, "Nonlinear Dynamics of Driven Relativistic Electron Plasma Waves, " Physical Review A 46, 5112 (1992).

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38. T. Katsouleas, W. B. Mori, C. Decker, T. C. Chiou, J. S. Wurtele, and G. Shvets, "Recent Work on Short Pulse Laser-Plasma Accelerators," Proceedings of the Particle Accelerator Conference, Washington, DC, May 17-20, 1993.

39. P. Davis, G. Hairapetian, C. Clayton, C. Joshi, S. Hartman, S. Park, C. Pellegrini, and J. Rosenzweig, "Quantum Efficiency Measurements of a copper Photocathode in an RF Electron Gun," Proceedings of the Particle Accelerator Conference, Washington, DC, May 17-20, 1993.

40. G. Hairapetian, P. Davis, C. E. Clayton, C. Joshi, S. Hartman, C. Pellegrini, and T. Katsouleas, "Experimental Demonstration of Plasma Lens Focusing," Proceedings of the Particle Accelerator Conference, Washington, DC, May 17-20, 1993.

41. C. Pellegrini, N. Barov, S. C. Hartman, S. Park, J. Rosenzweig, G. Travish, R. Zhang, P. Davis, C. Joshi, and G. Hairapetian, "Initial Operation and Beam Characteristics of the UCLA S-band RF Photoinjector," Proceedings of the Particle Accelerator Conference, Washington, DC, May 17-20, 1993.

42. G. Hairapetian, P. Davis, M. Everett, C. Clayton, C. Joshi, S. Hartman, S. Park, and C. Pellegrini, "Streak Camera Measurements of Electron Bunch Length from a Copper Photocathode in an RF Gun," Proceedings of the Particle Accelerator Conference, Washington, DC, May 17-20, 1993.

43. S. C. Hartman, N. Barov, S. Park, C. Pellegrini, J. Rosenzweig, G. Travish, R. Zhang, P. Davis, C. Joshi, and G. Hairapetian, "Emittance Measurements of the 4.5 MeV UCLA RF Photoinjector," Proceedings of the Particle Accelerator Conference, Washington, DC, May 17-20, 1993.

44. S. C. Hartman, C. Pellegrini, S. Park, J. Rosenzweig, G. Travish, R. Zhang, C. Clayton, P. Davis, M. Everett, C. Joshi, and G. Hairapetian, " Initial Measurements of the UCLA RF Photoinjector," Proceedings of the Workshop on High Intensity Electron Sources, (Legnaro, Padova, Italy, 1993).

LIST OF INVITED TALKS

Laser Acceleration in Laboratory Plasmas and Scaling to the Ionosphere, by T. Katsouleas, URSI National Radio Science Meeting, Boulder, CO, January 1987.

Overview of Plasma Based Accelerating Schemes, by C. Clayton, IEEE Particle Accelertaion Conference, Washington, DC, March 16-19, 2987.

Experimental Work at UCLA on the Plasma Beat Wave Accelerator, by C. Joshi, Workshop on New Developments in Particle Acceleration Techniques, Orsay, France, July, 1987.

Laser Acceleration of Particles, by C. Joshi, Ecole Polytechnique Federal De Lausanne, Lausanne, Switzerland, July 1987.

Electrostatic Mode Coupling of Beat Excited Plasma Waves, by C. Darrow, APS Annual Meeting, San Diego, November 1987.

Laser Driven Plasma Accelerators, by F. Chen, High Intensity Laser/Matter Interactions Conference at SPIE's OE/LASE '88 Conference, Los Angeles, CA January 1988.

Progress in Laser Particle Acceleration, by C. Joshi, Conference on Lasers and Electro-optic ('88 CLEO), Anaheim, CA, April 1988.

A Decade of Laser-Plasma Research at UCLA, by C. Joshi, 18th Anomalous Absorption Conference, Montreal, Canada, July 1988.

Progress in Laser Accelertion of Particles by C. Joshi, 10th Conference on the Application of Accelerators in Research and Industry, Denton, Texas, November 7-9, 1988.

The Physics of Beat Excited Plasma Waves, by C. Joshi, 18th Annual Anomalous Absorption Conference, Montreal, Canada, July 26-July 1, 1988.

The Nonlinear Optics of Plasmas, C. Joshi, ICTP Workshop on Plasma Physics, May 22-26, 1989, Trieste, Italy.

Wavebreaking of Longitudinal Plasma Oscillations, W. B. Mori, ICTP Workshop on Plasma Physics, May 22-26, 1989, Trieste, Italy.

Role of Plasma in Future Accelerators, T. Katsouleas, XVI International Conference on High Energy Accelerators, Tsukuba Japan, August 22-26, 1989.

Plasma Physics at the Final Focus, W. B. Mori, XVI XVI International Conference on High Energy Accelerators, Tsukuba Japan, August 22-26, 1989.

Plasma Wave Field Accelerators, T. Katsouleas, 2nd Workshop on New Methods of Charged Particle Acceleration, Yerevan, Soviet Armenia, Oct. 10-14, 1989.

Plasma Beat Wave Acceleration, C. Clayton, 2nd Workshop on New Methods of Charged Particle Acceleration, Yerevan, Soviet Armenia, Oct. 10-14, 1989.

Demonstration of Frequency Upshifting of Electromagnetic Radiation by Rapid Plasma Creation, C. Joshi, Laser Interaction and Related Plasma Phenomena Workshop, Monterey, CA, Nov. 6-20, 1989.

Plasma Physics at the Final Focus of High Energy Colliders. T. Katsouleas, 31st Annual APS-DPP Meeting, Anaheim, CA, Nov. 13-17, 1989.

Nonlinear Optics of Plasmas, C. Joshi, International Conference on Plasma Physics, New Delhi, India, November, 22-28, 1989.

Experimental Trends in Nonlinear and Relativistic Effects in Plasmas, C. Joshi, Topical Conference on Research Trends in Nonlinear and Relativistic Effects in Plasmas, La Jolla, CA , Feb. 5-8, 1990.

Phase Conjugation in Plasmas, C. Joshi, National Academy of Sciences: USA/USSR Workshop on Optical and Plasma Physics, UC Irvine/UCLA, March 1990.

Wakefield Accelerators: A Review, T. Katsouleas, APS Spring Meeting, Division of Physics of Beams, April 16-19, 1990, Washington, DC.

Generation of Tunable Radiation from Relativistic Ionization Front, W. B. Mori, 10th European School on Plasma Physics, Sept. 10-15, 1990, Ubilisi, USSR, also presented at Strong Microwaves in Plasmas, Sept. 16-20, 1990 in Suzdal, USSR.

Frequency Up-Conversion of Radiation Using Plasma Techniques, C. Joshi, International Dawson Symposium on the Physics of Plasmas, Sept. 23-25, 1990, Catalina Island, CA.

Nonlinear Problems in Beam and Laser Wakefield Accelerators, T. Katsouleas, US-Japan Workshop on Nonlinear Dynamics and Acceleration Mechanisms, Oct. 22-25, 1990, Tsukuba, Japan.

The Generation of Tunable Radiation Using a Relativistic Ionization Front, W. B. Mori, APS-DPP Annual Meeting, Nov. 12-16, 1990, Cincinnati, OH.