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D2 Paper II: Plasma emission in vacuum arc and RF-discharge plasma source, *Rev. Sci. Instrum.* 73(2) 754 2002.
D3 Paper III: Characteristics of a 13.56 MHz radiofrequency driven multicusp ion source, submitted for publication in *Plasma Sources Science and Technology.*
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LIST OF PUBLICATIONS AND PRESENTATIONS

Publications

1. D. Boonyawan, N. Chirapatpimol, N. Sanguansak, and T. Vilaithong 2000. *A 13.56 MHz multicusp ion source for high intensity Ar beam, **Rev. Sci. Instrum.** 71(2)* 1181.
2. D. Boonyawan, S. Davidov, B. Yotsombat, N. Chirapatpimol, and T. Vilaithong 2002 *Plasma emission in vacuum arc and RF-discharge plasma source*, ***Rev. Sci. Instrum.*** 73(2) 754.
3. D. Boonyawan, N. Chirapatpimol, and T. Vilaithong*: Characteristics of a 13.56 MHz radiofrequency driven multicusp ion source*, submitted for publication in ***Plasma Sources Science and Technology.***

Presentations

1. D. Korzec, **D. Boonyawan**, J. Engemann, *Microwave slot antenna type ultraviolet light source for fluid treatment*, The 8th International Symposium on the Science and Technology of Light Sources LS-8, Greifswald, Germany; 30. Aug. - 3. Sept. 1998.
2. D. Boonyawan, N. Chirapatpimol, and T. Vilaithong, *A 13.56 MHz multicusp ion source for high intensity Ar beam*, The 8th International Conference on Ion Sources, Kyoto, Japan, 6-10 Sep 1999.
3. D. Boonyawan, S. Davidov, B. Yotsombat, N. Chirapatpimol, and T. Vilaithong, *Plasma emission in vacuum arc and RF-discharge plasma source*, The 9th International Conference on Ion Sources, Oakland CA, USA, 3-7 Sep 2001.

4. D. Boonyawan, N. Tondee, P. Chaiwan, S. Amkaew, M. Rhodes and T.Vilaithong, *Beam diagnostics of Radiofrequency driven multicusp ion source*, International Workshop on Particle Beams & Plasma Interaction on Materials, Chiang Mai, THAILAND, 31 Jan-1 Feb 2002.

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