रेडियो आवृत्ति प्रणाली

12

रिक्त कैथोड आधारित शीत वायुमंडलीय प्लाज्मा (HC-CAP) उपकरणों के लिए स्वदेशी आरएफ प्रणालियां

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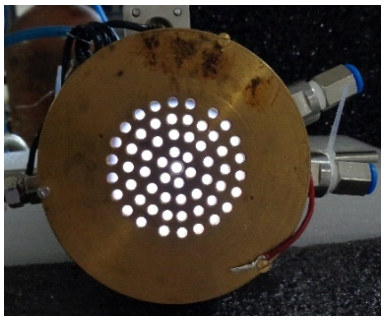

~60 W RF पावर पर 16cm2 प्रभावी प्लाज्मा क्षेत्र वाला युक्त एचसी सीएपी उपकरण

ABSTRACT

खोखले कैथोड आधारित शीत वायुमंडलीय प्लाज्मा (एचसी-सीएपी) उपकरणों को एल एंड पीटीडी द्वारा स्वच्छता अनुप्रयोग के लिए एक आशाजनक तकनीक के रूप में प्रदर्शित किया गया है। रेडियो आवृत्ति शक्ति को एचसी-सीएपी उपकरणों से युग्मित करके शीत प्लाज्मा को उत्पन्न किया जाता है। एसीएनडी ने इस उपकरणों के लिए स्वदेशी रेडियो आवृत्ति प्रणालियोंको विकसित किया है। दो प्रकार की प्रणालियाँ विकसित की गई हैं, अर्थात् / नामत:, एक मैनुअल प्रतिबाधा मिलान नेटवर्क (आईएमएन) के साथ 13.56 मेगाहट्र्ज 250 W रेडियो आवृत्ति प्रणाली, और दूसरी स्वचालित प्रतिबाधा मिलान नेटवर्क (ऑटो-आईएमएन) के साथ 2 से 30 मेगाहट्र्ज तक ट्यून करने योग्य 200 W रेडियो आवृत्ति स्रोत (प्रणाली)। शीत प्लाज्मा, रेडियो आवृत्ति प्रणाली के लिए एक गतिशील भार प्रतिबाधा प्रस्तुत करता है, जो सर्कुलेटर की अनुपस्थिति में इसके डिजाइन को और अधिक चुनौतीपूर्ण बनाता है। यह पेपर वायुमंडलीय दबाव वाले शीत प्लाज्मा उत्पादन के लिए लागत प्रभावी और अनुकूलित रेडियो आवृत्ति प्रणालियों के विकास के विवरण पर चर्चा करता है।

Radio Frequency System

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Indigenous RF Systems for Hollow Cathode Based Cold Atmospheric Plasma (HC-CAP) Devices

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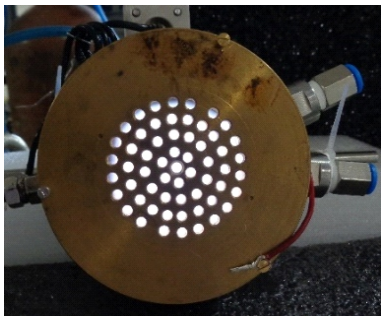

HC CAP device with effective plasma area 16 cm^2 at ~ 60 W RF power.

ABSTRACT

Hollow Cathode based Cold Atmospheric Plasma (HC-CAP) devices have been demonstrated as a promising technology by L&PTD for sanitization application. Cold plasma is generated by coupling RF power to the CAP devices. ACnD has developed indigenous RF systems for these devices. Two types of systems have been developed, viz. a 13.56 MHz 250W RF system with manual impedance matching network (IMN), and a 200W RF source tunable from 2 to 30 MHz with Automatic Impedance Matching Network (Auto-IMN). The cold plasma presents a dynamic load impedance to the RF system, which makes its design more challenging in absence of circulator. This paper discusses the details of development of cost effective and customized RF systems for atmospheric pressure cold plasma generation.

KEYWORDS: *Amplifier, Hollow Cathode Cold Atmospheric Plasma (HC-CAP), Impedance matching, Radio frequency, Power measurement*

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Introduction

RF power sources are used for driving plasma devices for various applications e.g. cleaning, coating, surface activation, disinfection or decontamination of pathogens, sputtering etc. The commercially available RF systems are expensive and are locally non-repairable and non-maintainable. For hollow cathode based cold atmospheric plasma (HC–CAP) [1,2] devices developed by L&PTD, the RF power requirement is generally in the range of 100 to 200 W. To mitigate above challenges, ACnD has designed and developed indigenous RF power systems, as import substitutes for cold plasma generation. The development of two types of RF systems viz. a 13.56 MHz RF system with manual matching network, and a 2 to 30 MHz tunable RF system with auto matching network are described in the following sections.

The 13.56 MHz 250W RF systems with manual impedance matching network

This indigenous, standalone 13.56 MHz RF power system is designed, developed and optimized for high efficiency and cost effectiveness for use with different cold atmospheric plasma devices (CAP) designed and developed by L&PTD [1,2]. The indigenously developed subsystems include, a crystal oscillator with low power driver, high gain & high efficiency power amplifier [3,4], high directivity-directional coupler based digital power measurement [5,6], DC bias supplies, interlock and protection circuit and a customized L-type impedance matching network. Fig.1 shows the architecture of 13.56 MHz RF system for HC-CAP. The MOSFET based main power amplifier is biased in class C configuration with tuned resonant circuit at its input and output stages to reduce the harmonic contents in RF power. A novel protection scheme based on reflected power and MOSFET junction temperature is used to protect RF amplifier against continuous high reflected power. All these subsystems are housed in a single standard 5 U rack as a standalone and portable RF power system.

The important & critical performance parameters achieved, and salient features of RF system are:

- Efficiency (DC to RF): > 70%.
- Efficiency (AC to RF): > 64%.
- Load variations: No damage with Short and Open load termination.
- High directivity directional coupler based RF power measurement.
- EMI/EMC compatible.
- Modular, Portable & Field deployable.

The high AC to RF and DC to RF efficiencies have led to reduced electrical power consumption further leading to low operational cost and low thermal load, respectively. The RF power source incorporates an independent RF signal source thereby no external signal generator is needed for its operation. Being tolerant to load variations/VSWR changes assures ruggedness. An in-house designed and developed high directivity bi-directional coupler based RF power measurement [5,6] assures accurate power measurement. EMI/EMC compatibility ensures non-interference with other electronic systems. Its modularity ensures easy replicability & maintainability.

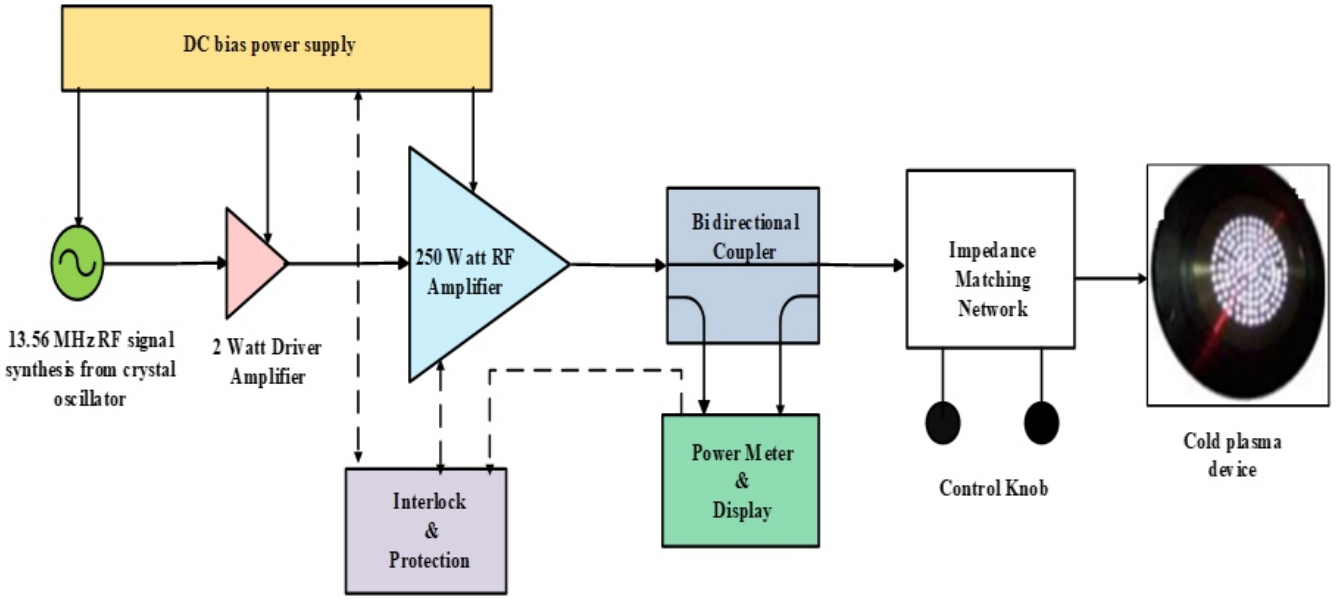
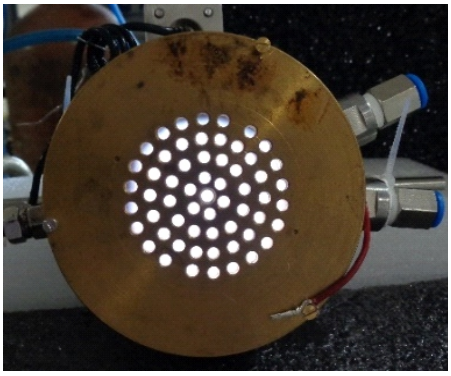


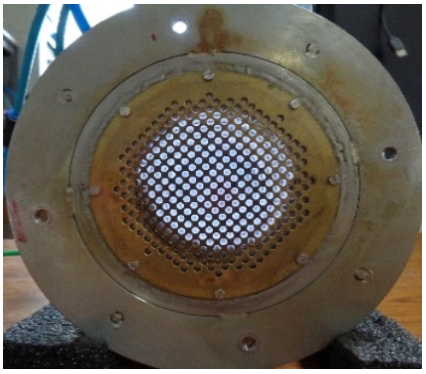
Fig.1: Architecture 13.56 MHz RF system for HC-CAP.

Fig.2: 13.56 MHZ, 250 W RF source.

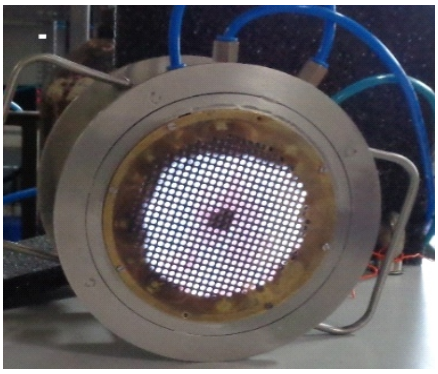
Fig.3: Impedance matching network.



HC CAP device with effective plasma area 16 cm^2 at ~ 60 W RF power.



HC CAP device with effective plasma area 50 cm^2 at ~ 90 W RF Power.



HC CAP device with effective plasma area 80 cm^2 at ~ 140 W RF Power.

Fig.4: Three different HC-CAP devices driven by indigenous RF power system and its IMN.

An L-type impedance matching network (IMN) has been designed and developed to match the impedance of HC-CAP device to 50 Ohm output impedance of 13.56 MHz RF system. The impedance of HC-CAP device changes dynamically while transiting from Argon gas stage into its plasma stage. These changes are accommodated by IMN to have stabilized cold plasma. The architecture of 13.56 MHz RF system customized and coupled to HC-CAP device via impedance matching network is shown in Fig.1.

Fig.2 shows the RF system developed and its impedance matching network is shown in Fig.3. During field trials, the 13.56 MHz, 250 W system with L-type impedance matching network has been successfully coupled with three different HC CAP devices available at L&PTD having different diameters. Argon plasma was successfully generated in each of these devices (Fig.4) and was found to be stable against load variations and argon gas flow rate changes.

Variation in forward and reflected RF power coupled with the CAP device of 185 mm diameter over a period of time (11.15 Hrs to 16 Hrs) is shown in Fig.5. RF power and gas flow requirement for three different HC-CAP devices are listed in Table 1.

RF system with He, Ar & O_2 based HC-CAP

The same 13.56 MHz, 250 W RF system was also coupled with another plasma device having a different configuration, shown in Fig.6, and full intensity plasma was observed with forward RF power of 94 W. The plasma was generated with combination of Helium, Argon & Oxygen gases.

13.56 MHz 50 W RF system

A number of other CAP devices catering to different applications require less than 50 W of RF power at 13.56 MHz. Therefore, a standalone 50 W RF system, shown in Fig.7, has also been designed and developed. It is a low-cost, portable, compact (19", 3U) light weight unit.

200W RF source tuneable from 2 to 30 MHz with Automatic Impedance Matching Network (Auto-IMN)

ACnD, with support of L&PTD, has also developed a 200W, 2 to 30 MHz RF source incorporating an automatic impedance matching unit [7]. The auto-matching system which had to be imported at a premium cost has been developed in house including the high power components. Fig.8 shows the source coupled to HC-CAP device at L&PTD.

Wideband RF power amplifier has been developed so that plasma can be generated at both 13.56 MHz and 27.12 MHz. The system incorporates a Direct Digital Synthesis IC, which has been programmed to generate required RF input signal over the frequency range. The high power RF source has a dynamic range of 31.5 dB. Adequate protection has been provided for the RF source against over-drive, over-temperature and high reflected power. The input DC supply voltage and current are controllable from local panel for the RF source. The important parameters of RF source are displayed on the local panel, including forward power, reflected power, temperature, drain voltage and current. These parameters are accessible remotely using Ethernet controller.

The automatic impedance matching network is realized by an in-house developed tunable LC network, which incorporates, high power RF air core variable capacitors and inductor. The value of the capacitors is varied by driving geared stepper motors. An algorithm has been developed for the

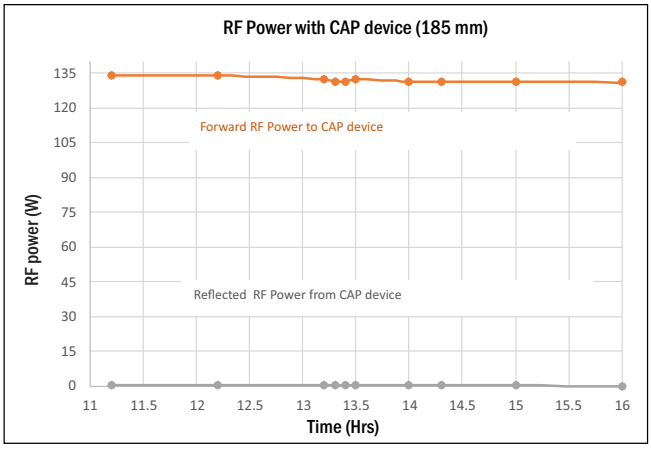


Fig.5: Variation of RF power with CAP device with time.

Table 1: RF Power with CAP devices of different diameters.

Parameters	CAP (85 mm)	CAP (130 mm)	CAP (185 mm)
Frequency (MHZ)	13.56	13.56	13.56
Forward Power (W)	60	80	140
Reflected Power (W)	3	5	10
Gas	Argon	Argon	Argon
Gas flow rate (LPM)	8	12	20
CAP Assembly (Dia. in mm)	85	130	185

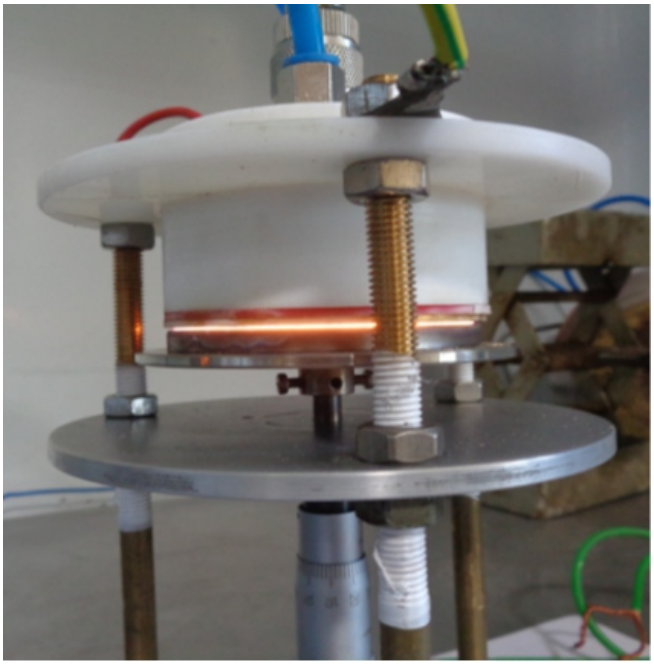


Fig.6: Cold plasma with combination of Helium, Argon & Oxygen gases.

measurement of load impedance and control of matching network which ensures matching to 50 ohm. The firmware has been written using C++ programming language for microcontroller. The control algorithm for auto-impedance matching may be tuned for other applications like antenna tuning and communication applications.

This system was also integrated with three different HC-CAP devices having effective plasma generation area of ~16 cm^2, ~ 50 cm^2 and ~ 80 cm^2 at L&PTD, BARC. Argon gas was used to generate plasma in all these cases whereas, Ar gas flow rate was changed from 15 to 30 LPM and power was also varied. The generated plasma remained stable under the operating window and no significant fluctuation was observed during the course of experiments. Generated Ar plasma also remained stable against load variations.

Fig.7: 13.56 MHz, 50 W RF power source (3U).

An auto-igniting system has been developed and integrated with the plasma device. With the auto-ignition system, discharge from the plasma torch could be started without any manual intervention. This auto-ignition system is a very useful feature as often striking the initial discharge requires some form of manual intervention. This is especially the case when HC-CAP devices age, and when physical access to the device is difficult, e.g. when the device is put into fume hoods/containments etc. It is planned to carry out more field trials to further optimize the robustness of the matching algorithm and also the form factor.

Conclusions

A standalone and plug and play type 13.56 MHz RF system with manual matching network, and a 2 to 30 MHz tunable RF system with auto matching network and have been totally indigenously developed. These systems have been successfully integrated with HC-CAP devices for plasma generation. The generated plasma may be used for sanitization or disinfection of pathogens. These RF systems are versatile and may also be used for generation of other types of plasma. RF amplifier technology with manual-IMN has also been customized for 50 W for other plasma applications.

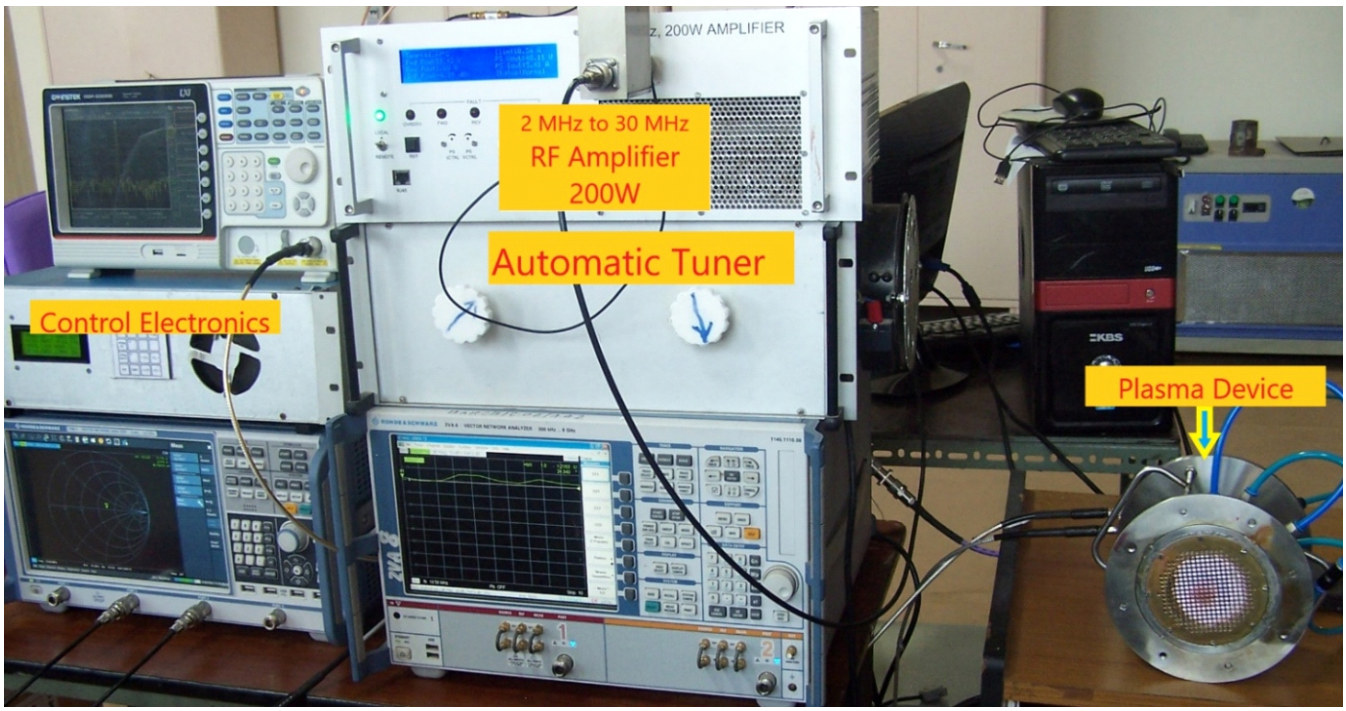


Fig.8: 2-30 MHz, 200W RF source with Automatic Impedance Matching & Auto-Igniting system integrated with the plasma device. The blue-pink glow state of Ar plasma can be seen.

Acknowledgements

The authors would like to sincerely thank the team of L&PTD and Dr. Archana Sharma, Director, BTDG. The authors acknowledge ttechnical support and efforts provided by Shri Hitesh Kadam, Shri Jagadish Bowlekar, Smt. Charulata Shinde, Shri Mayur M Sutar and other colleagues who have helped on various occasions.

The authors are very much thankful to Shri U.D. Malshe, Director, MRG and Shri Vivek Bhasin, Director, BARC for his constant encouragement and continued support for this valuable BARC program.

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