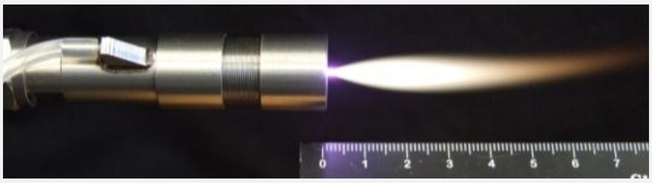
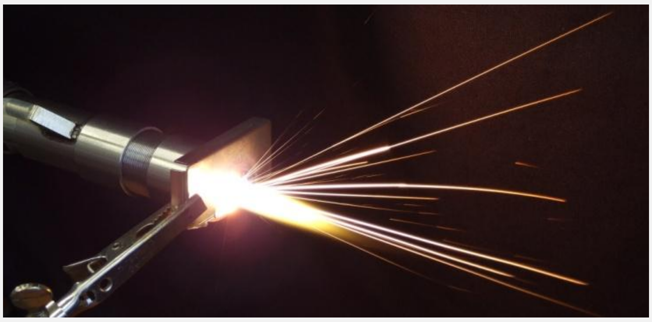
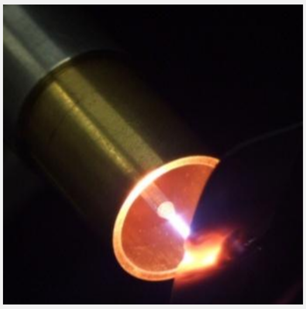
HEUERMANN
HF-Technik GmbH

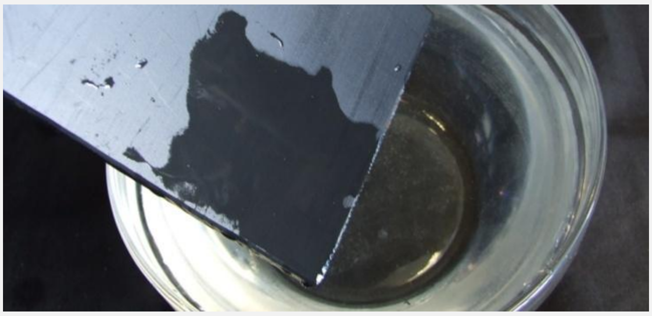
Application Notes

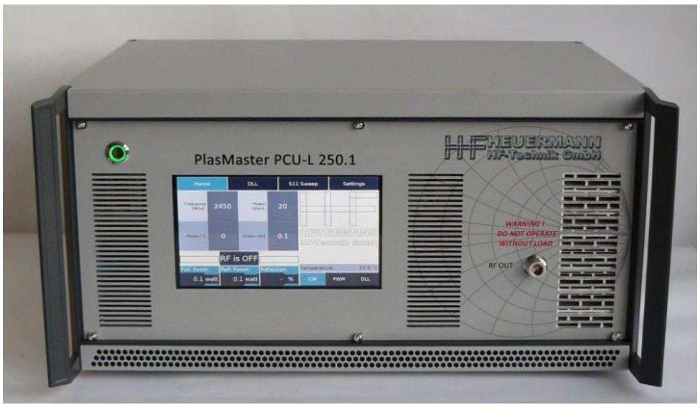
Plasma Products











November 2019

Version 3.0

Contents

0. Introduction

The numerous advantages of plasma in activating and cleaning of plastic and metal surfaces prior to adhesive bonding and painting processes have led to an increasing in-line integration of such systems in industrial processes over the past few years. In this manner, anticorrosive or adhesion promoter layers can be applied without the use of solvents in an environmental friendly manner. The in-line integration enables an efficient production flow and is thus time and cost saving.

Conventional atmospheric plasma generation generally relies on a high voltage discharge (5 – 15 kV at 10 kHz – 20 MHz) to produce a pulsed electric arc. After ignition, or rather initial arcing, a matching network is generally used to assure an optimal operating condition while sustaining the plasma. Using a process gas (preferably oil-free compressed air), the plasma is carried out of the casing to form a plasma jet.

Heuermann HF-Technik GmbH uses an innovative concept of igniting and sustaining plasma under atmospheric conditions using radio frequency signals at 2.45 GHz. The concept of these so called microplasmas is principally known for quite a number of years. Our novel systems however require merely a few ten Watts of microwave power for ignition and perform automated plasma matching within the license-free industrial, scientific and medical (ISM) frequency band at 2.45 GHz, thus enabling optimal performance under all operational conditions.

The present systems are capable of coping with microwave power levels of over 2 kW using different process gases ranging from compressed air to inert gases such as argon.

These novel systems offer the known advantages of plasma treatment (such as heating, ionization and emission of reactive particles) with the difference, that the inclination of ionization and emission of reactive particles is principally higher at 2.45 GHz. Furthermore, the implemented ignition concept, based on an impedance and voltage transformation, results in an electrode-friendly plasma production without arcing, increasing its lifetime and delivering purest plasma, where the high voltage generation is confined to a few millimeters at the tip of the electrode. In combination with the absolutely potential free casing, the system is easy to handle and can be readily integrated in test or production facilities.

A few typical applications are presented in the following pages, including the experimental setups. Please feel free to contact us for further information on specific applications or systems ranging from feasibility studies under laboratory conditions to industrial facilities (we have a R&D cooperation with a leading producer of industrial plasma facilities).

Process gas	Application	Power level	Jet	Comments
Air / nitrogen	Activation, activation, rapid heating	40 – 250 W	PS	
	Rapid activation, cleaning and heating	80 – 500 W	PC-SF3	
	Coating with powder or wire, Fluid treatment (activation, heating or vaporization)	80 – 500 W	PC-SF4	
	Very rapid activation, cleaning, heating, and melting	1400 – 3000 W	PS-MJ	Magnetron jet, broad plasma
Argon / Varigon	Activation (low temperature)	2 – 10 W	MiniJet-R	Manual ignition
	Activation (low temperature)	5 – 100 W	PS-Ar	
	Cutting, welding	50 – 250 W	PC-B	
	Same as PC-SF4, but with higher power density	60 – 250 W	PC-SF2	
	Same as PC-SF3, but with much higher power density	80 – 500 W	PC-SF5	
	Same as PC-SF4, but with much higher power density	80 – 500 W	PC-SF6	
No gas	Low pressure chamber	50 – 500 W	CC	Coupler, tested up to 400 W

Tab. 1: Overview of the different plasma jets, operation conditions and possible applications

1. Surface Activation

<u>Experiment:</u> Surface activation, in this case plastic
Applicable for metallic and non-metallic materials
Related applications: pretreatment for glues, paints, and coating

Setup

<u>Equipment:</u> Generator: PlasMaster PCU-L 200.4

Applicator: PS jet

<u>Test conditions:</u> up to 200 W at 2.45 GHz using air at 10 sl/min

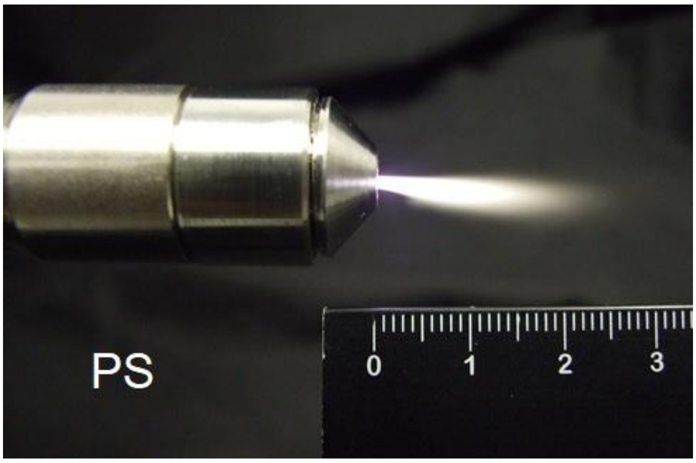


Fig. 1: The PS jet at 200 W with an airflow of app. 10 sl/min

Results

A rapid, homogenous activation was achieved

+ No further treatment required
+ No process gas required
+ Airflow easily realized with simple compressor
+ Fast and effective activation
+ Rate of treatment easily scalable over RF power and air flow

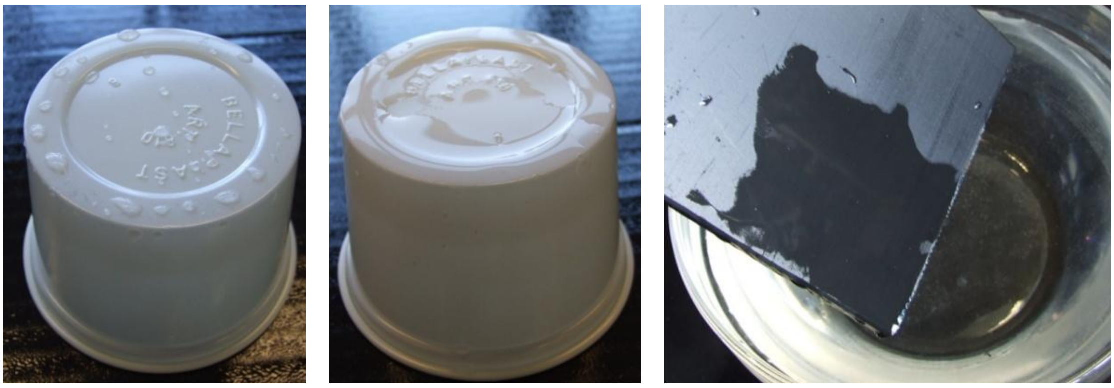


Fig. 2: Plastic cup, before (left) and after (centre) activation
as well as partly activated plastic sheet (right)

<u>Experiment:</u>	Surface activation, in this case polyethylene Applicable for metallic and non-metallic materials Related applications: pretreatment for glues, paints, and coating

Setup

<u>Equipment:</u>	Generator:	PlasMaster PCU-L 200.4
	Applicator:	PS jet
<u>Test conditions:</u>	160 W at 2.45 GHz using air at 10 sl/min	

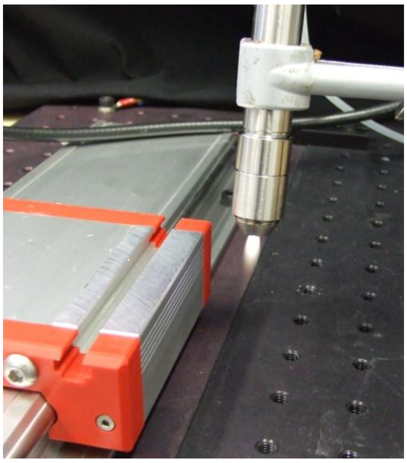


Fig. 3: The PS jet with linear bearing

Results

A rapid, homogenous activation was achieved

+ No further treatment required
+ No process gas required
+ Airflow easily realized with simple compressor
+ Fast and effective activation
+ Rate of treatment easily scalable over RF power and air flow

Fig. 4: Two activated stripes on a polyethylene specimen, treated with the PS jet

Experiment: Surface activation, in this case noble metal
Applicable for metallic and non-metallic materials
Related applications: pretreatment for glues, paints, and coating

Setup

Equipment: Generator: PlasMaster PCU-L 200.4

Applicator: PS jet

Test conditions: 100 W at 2.45 GHz using air at 7 sl/min

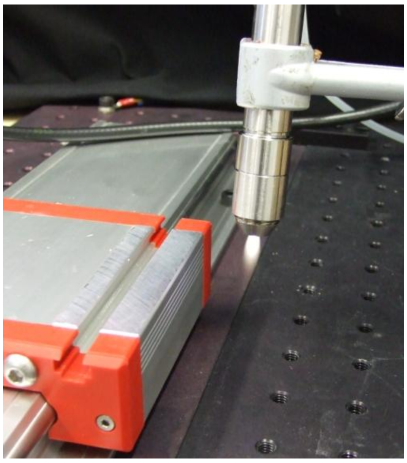


Fig. 5: The PS jet with linear bearing

Results

A rapid, homogenous activation was achieved

+ No further treatment required
+ No process gas required
+ Airflow easily realized with simple compressor
+ Fast and effective activation
+ Rate of treatment easily scalable over RF power and air flow
+ Surface tension improved to **72 mN/m** from 35 mN/m

untreated area

treated area

Fig. 6: Two activated stripes on a noble metal specimen, treated with the PS jet

Experiment: Surface activation, in this case PTFE plate and porcelain
Applicable for metallic and non-metallic materials
Related applications: pretreatment for glues, paints, and coating

Setup

Equipment: Generator: MiniJet 10 W generator

Applicator: MiniJet-R

Test conditions: 10 W at 2.41 GHz using argon 0.9 sl/min

Fig. 7: Microwave plasma jet MiniJet-R with argon as process gas

Results

A rapid, homogenous activation was achieved

+ No further treatment required

+ Low consumption of process gas required

+ Fast and effective activation

+ Surface tension improved to **72 mN/m**

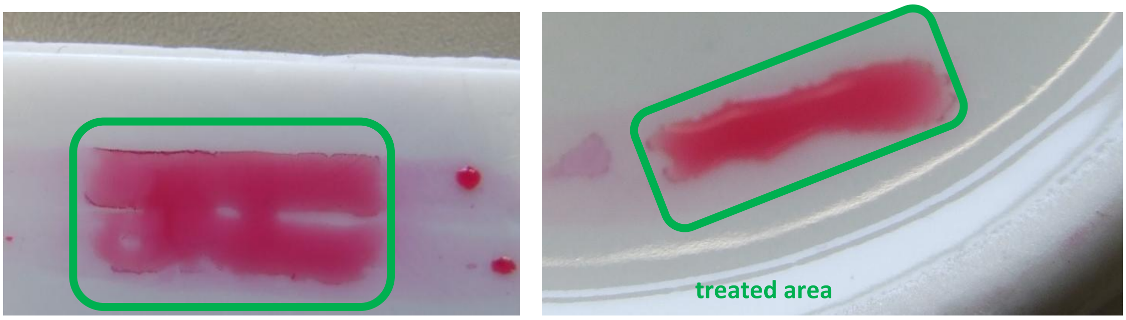


Fig. 8: Activated stripes on a PTFE plate (left) and a porcelain cup, treated with the MiniJet-R

Experiment: Surface activation, in this case PTFE plate
Applicable for metallic and non-metallic materials
Related applications: gluing

Setup

Equipment: Generator: MiniJet 10 W generator / PlasMaster PCU-L 200.4

Applicator: MiniJet-R / PS jet

Test conditions: MiniJet-R: 10 W at 2.41 GHz using argon at 0.9 sl/min
PS jet: 150 W at 2.45 GHz using air at 8 sl/min

Fig. 9: Microwave Plasmajet MiniJet-R with argon as process gas (left) and PS jet with linear bearing

Results

A rapid, homogenous activation was achieved

+ No further treatment required
+ Low consumption of process gas required
+ Fast and effective activation
+ Fast and effective activation
+ max. strain could be doubled as compared to untreated gluing

Fig. 10: Activated stripes on a PTFE plate (left) and stress test, treated with the MiniJet-R and the PS jet

2. Surface Cleaning

Experiment: Cleaning a surface, in this case a 5 cent coin
Applicable to metallic and non-metallic surfaces
Related applications: disinfection of surgical surfaces and devices

Setup

Equipment: Generator: PlasMaster PCU-L 200.4

Applicator: PS jet

Test conditions: 150 W at 2.45 GHz using air at 8 sl/min

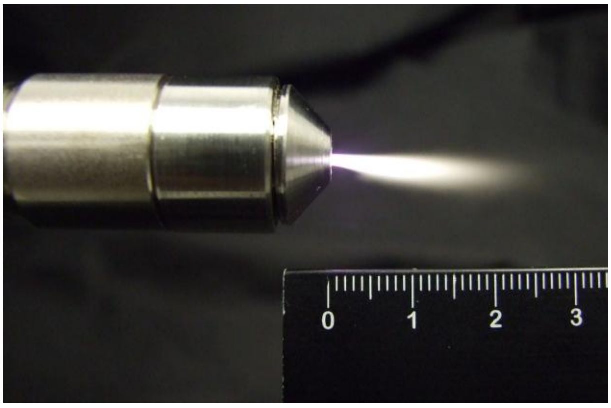


Fig. 11: The PS jet

Results

All residues of dirt, fat and impurities could be removed by running microwave plasma jet over a coin

+ No further treatment necessary

+ Fast and effective cleaning

+ Rate of treatment easily scalable over RF power (plasma size and energy)

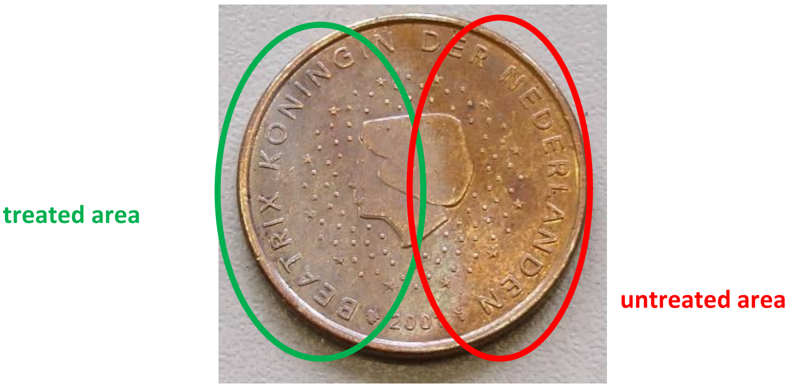


Fig. 12: Coin with cleaned surface using microwave plasma at 2.45 GHz

3. Coating

Experiment: One-step coating with metallic powders, in this case a tin coating on a silver wire
Applicable for metallic and non-metallic materials
Related applications: activation, coating and sputtering

Setup

Equipment: Generator: PlasMaster PCU-L 200.4

Applicator: Microwave plasma jet PC-SF2

Test conditions: < 50W at 2.45 GHz using argon as process gas and propellant at 1 l/min

Solder alloy: SN100C – SnCuO, 7Ni; T3 (45 – 25 µm)

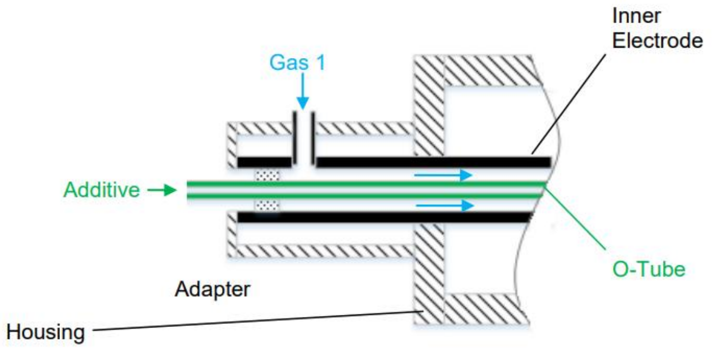


Fig. 13: Introducing soldering powder (tin) and process gas to the microwave plasma jet (PC-SF2)

Results

Homogenous coating in a single step

+ No further treatment necessary
+ Fast and effective coating
+ Optimal activation, since powder is sent completely through plasma
+ Minimum powder wastage, not applied powder easily collectable for re-use
+ Rate of coating easily scalable over RF power and gas flow (plasma size and energy)

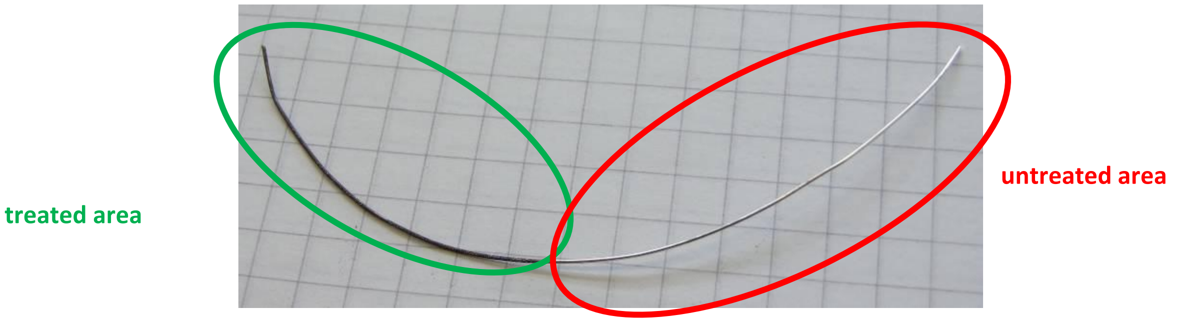


Fig. 14: Silver wire, coated with a solder powder using microwave plasma at 2.45 GHz

4. Cutting

Experiment: Cutting of thin metal sheets
Applicable for metals, no prior treatment necessary, oxide layers easily bypassed
Related applications: soldering, furthermore melting of radioactive material (plasma temperature well over 3000 °C)

Setup

Equipment:	Generator:	PlasMaster PCU-L 200.4
	Applicator:	customized nozzle plasma jet
Test conditions:	200W at 2.45 GHz using argon as process gas at 0.1 l/min	

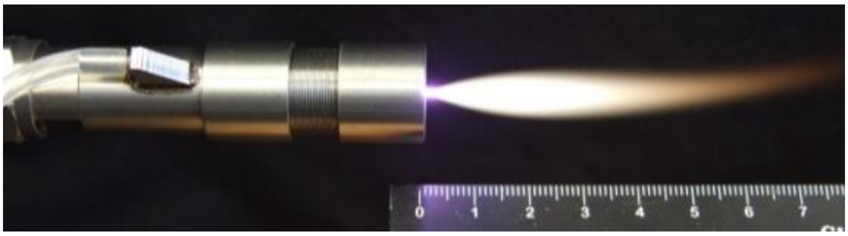


Fig. 15: Customized nozzle plasma jet (with argon at 0.2 sl/min) at 200 W for high power and high temperature applications

Results

Cutting of thin metal sheets

+ No prior treatment necessary
+ Oxide layers easily bypassed without influence on cutting process
+ Rate of cutting easily scalable over RF power and gas flow rate

Fig. 16: Cutting a thin brass sheet using microwave plasma at 2.45 GHz

5. Voluminous Plasma

Experiment: Generation of a voluminous plasma
Applicable for plasma chambers for activation or surface treatment
Related applications: gluing, disinfection of medical instruments

Setup

Equipment: Generator: PlasMaster PCU-L 200.4

Applicator: customized plasma applicator

Test conditions: < 50 W at 2.45 GHz using argon as process gas at 0.01 bar

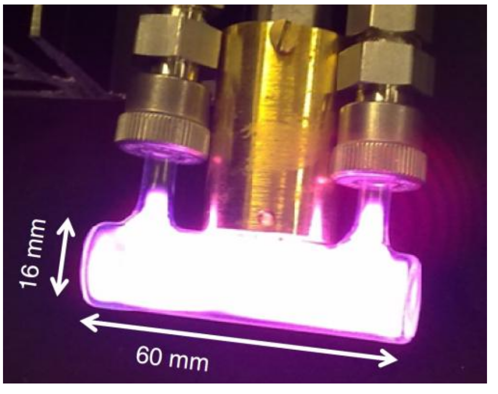


Fig. 17: Voluminous plasma with customized transformer at 50 W with argon at 0.01 bar

Results

Larger plasma clouds for treatment

+ No prior treatment necessary for treatment

+ Size, intensity and temperature of plasma scalable over RF power

6. Very Rapid or High Power Activation

Experiment: Activation of glass

Setup

Equipment:	Generator:	PlasGen PG-L 3000.1
	Applicator:	PS-MJ MagJet
Test conditions:	2.5 kW at 2.45 GHz with air as process gas at 30 sl/min, 4 cm distance and at 10 cm/s	
Test structures:	Glass	

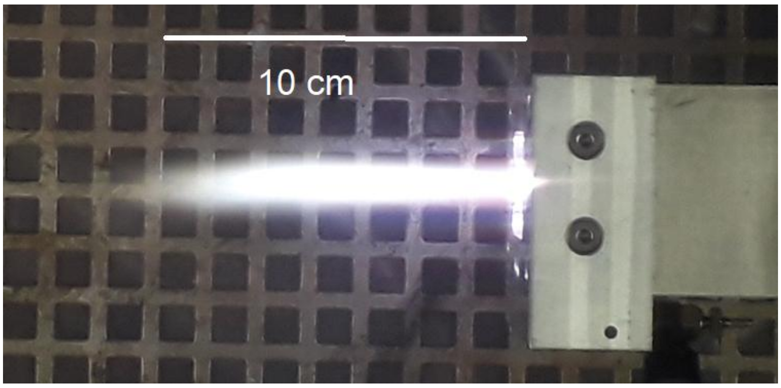


Fig. 18: The PS-MJ MagJet at 2.5 kW

Results

A rapid, homogenous activation was achieved

+ No further treatment required
+ Low consumption of process gas required
+ Fast and effective activation
+ Surface tension improved to **72 mN/m**

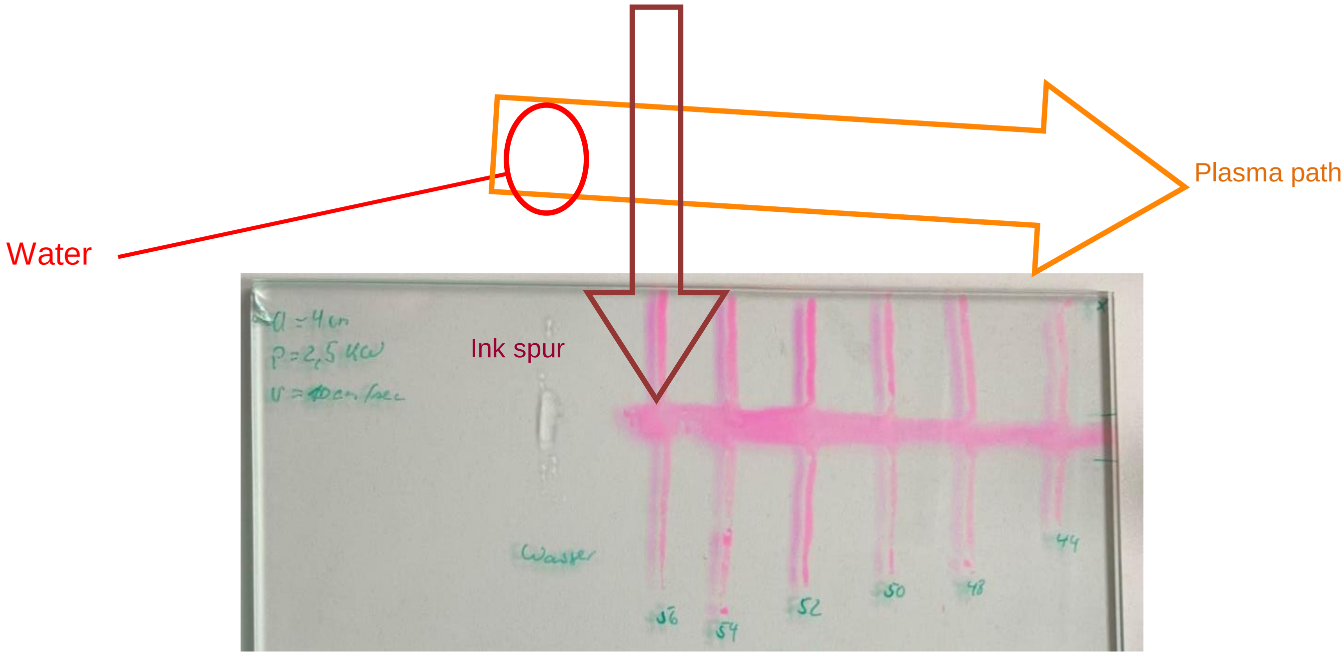


Fig. 19: Activated glass with an improvement in the surface tension to over 72 mN/m

7. Very Rapid or High Power Cleaning

Experiment: Efficient and quick cleaning of production tools

Setup

Equipment: Generator: PlasGen PG-L 3000.1

Applicator: PS-MJ MagJet

Test conditions: 2.5 kW at 2.45 GHz with air as process gas at 30 sl/min, 4 cm distance and at 5 cm/s

Test structures: Cast Iron

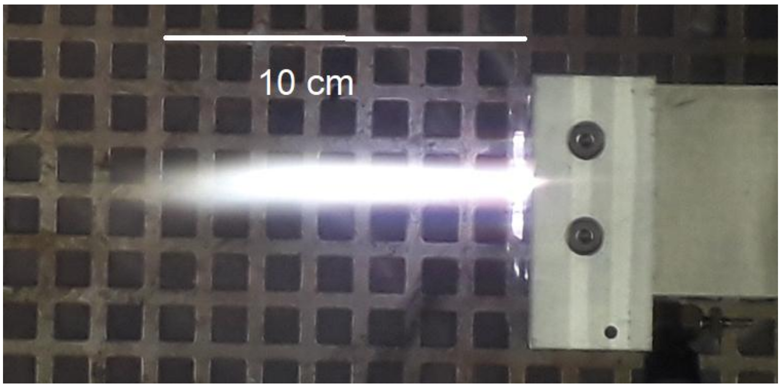


Fig. 20: The PS-MJ MagJet at 2.5 kW

Results

A rapid, homogenous cleaning was achieved in a single run

+ No further treatment required
+ Low consumption of process gas required
+ Fast and effective activation

Fig. 21: Production tool prior to cleaning (left) and after a single run with the PS-MJ MagJet at 2.5 kW

8. ESD/EMC Tests

Experiment: Effect of microwave plasma in the vicinity of and on active and passive, electro-sensitive components

Setup

Equipment:	Generator:	PlasMaster PCU-L 200.4
	Applicator:	Microwave plasma jet PC-B

Test conditions: > 100 W at 2.45 GHz using argon as process gas at 1 sl/min

Test structures: 6 capacitors

(left, 0402, top to bottom: 0.22 µF/10 V; 0.22 µF/6.3 V; 0.47 µF/6.3 V; right, 0603, top to bottom: 2.2 µF/10 V; 0.22 µF/6.3 V; 0.47 µF/6.3 V);

Bottom left: Schottky diode (BAT63, Ud = 0.2 V)

Bottom right: transistor (BFP620, $U_{ce,max}$ = 12 V, $U_{be,max}$ = 2 V)

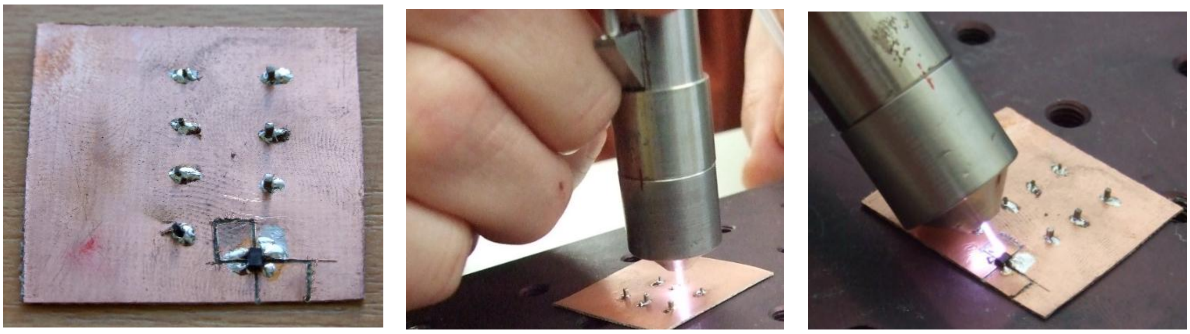


Fig. 22: *Left:* test circuit with 6 passive and two active components; *middle:* treatment of a passive component; *right:* treatment of an active component

Results

No change in the electrical characteristics after direct plasma treatment.

+ No change in capacitance or resistance value of capacitors

+ No change in diode voltage of 0.2 V, although casing was damaged during plasma treatment (Fig. 19, left)

+ No change in characteristic voltages of transistor (collector-emitter or collector-base) although casing severely damaged during plasma treatment (Fig. 19, right)

+ Spurious from the power supply were measured at about -70 dBm (70 µV at 50 Ohm)

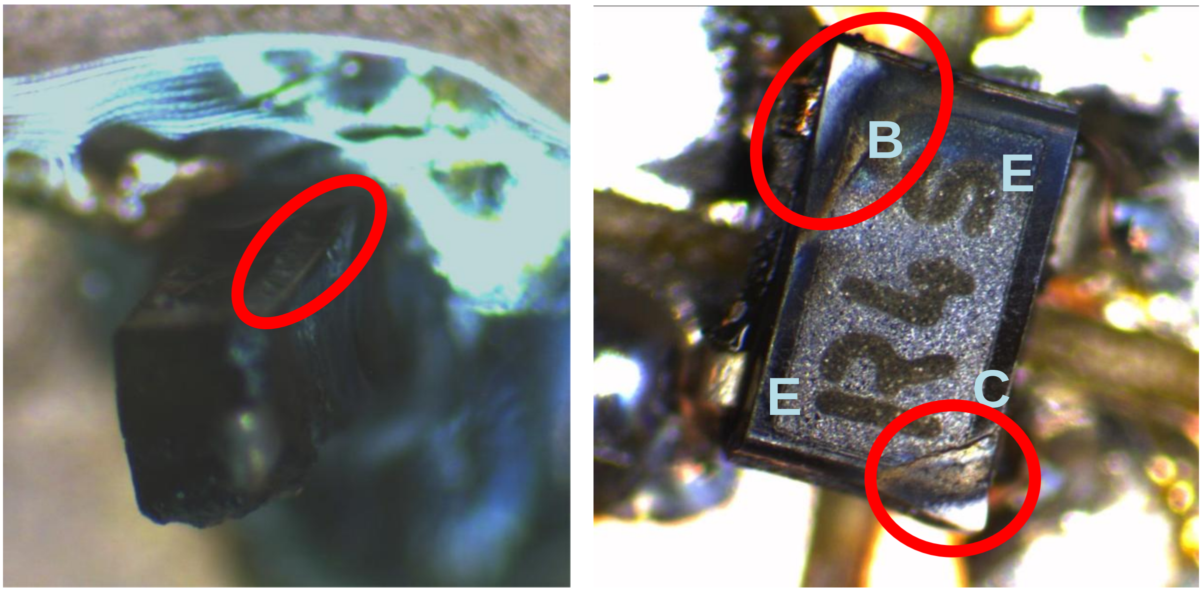


Fig. 23: Active components after direct plasma treatment
(Schottky diode on the left, transistor on the right)

9. Optical Spectra of the Plasma Jets

Experiment: Optical spectra of the Plasma PS Jet and the PS-Ar Jet

Setup

Equipment: Generator: PlasMaster PCU-L 200.4

Applicator: Microwave plasma jet PS jet (air)

Microwave plasma jet PS-Ar (argon)

Test conditions: Two optical spectra recorded for each jet at 2.45 GHz

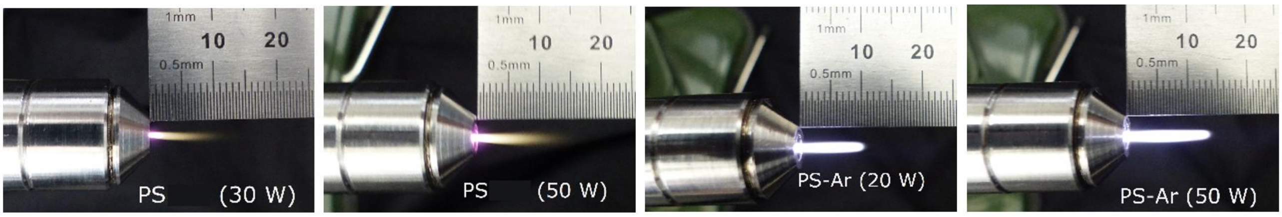


Fig. 24: *Left to right:* PS jet at 30 W and 50 W respectively (air flow at 2 sl/min), and PS-Ar at 20 W and 50 W respectively (argon flow at 2 sl/min)

Results

Low emission rates in optical and ultraviolet ranges

+ Lower emission in optical and UV regions, correspond to smaller sized plasma (exposure time **120 s**, Fig. 21, left)

+ Optical emission relatively higher, correspond to larger sized plasma (exposure time **12 s**, Fig. 21, right)

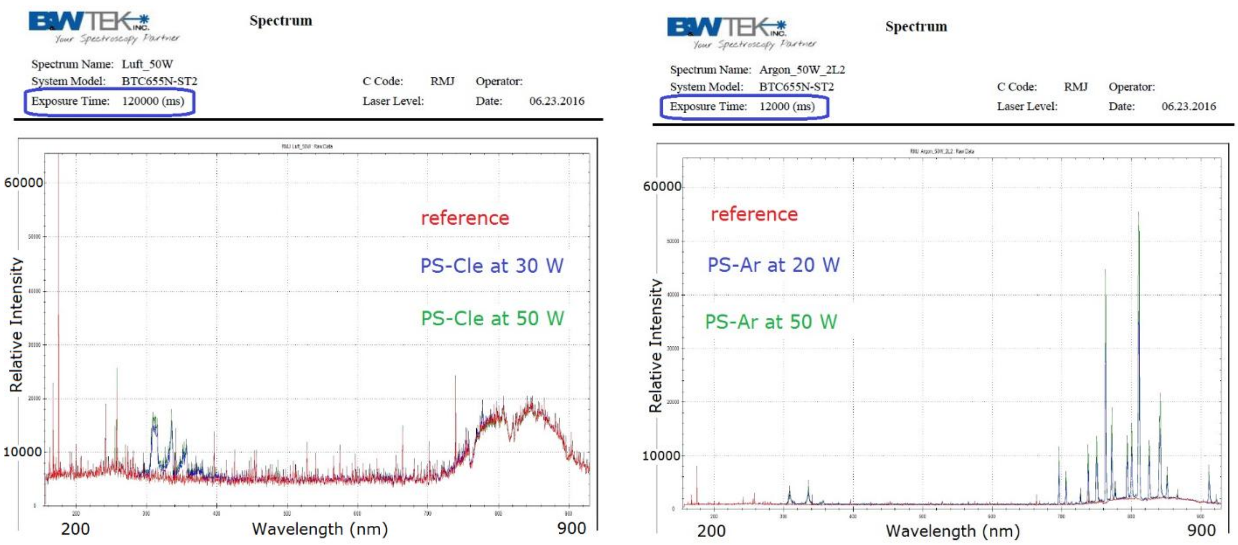


Fig. 25: Optical spectra of plasma jets, PS jet at 30 W and 50 W respectively (air flow at 2 sl/min, *left*), and PS-Ar 20 W and 50 W respectively (argon flow at 2 sl/min, *right*)

No spectral lines from the Cu-electrodes can be detected!

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