Additively Manufactured Anodes in a Relativistic Planar Magnetron

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Abstract: *Recent experiments on the UM Recirculating Planar Magnetron (RPM), have explored the use of 3-D printed components in a HPM system. The system was driven by MELBA-C, a Marx-Abramyan system which delivers a -300 kV voltage pulse for 0.3-1.0 us, with a 0.13-0.31 T axial magnetic field applied by a pair of electromagnets. Anode blocks were printed from Water Shed XC 11122 photopolymer using a stereolithography process, and prepared with either a spray-coated or electroplated finish. Both manufacturing processes were compared against baseline data for a machined aluminum anode, demonstrating improvements in pulsed magnetic field penetration, while maintaining similar performance for power output, oscillation frequency, and mode stability. Residual gas analysis indicated similar outgassing behavior, with a higher incidence of gas spikes for the plastic anodes. With over 100 shots on each 3-D printed structure, there was no evidence of beam-induced degradation.*

Keywords: additive manufacturing; 3-D printing; HPM; high power microwave; recirculating planar magnetron; magnetron; electroplating; thermal spray

Introduction

Additive manufacturing techniques have the potential to provide a number of benefits to high power microwave (HPM) systems, including weight reduction, rapid prototyping, or the fabrication of extremely complex shapes. An obvious concern is that these benefits may come at the cost of a reduction in performance or durability. To begin addressing this issue, we investigated the performance of two 3-D printed anode structures in a relativistic planar magnetron [1]. Previous work has looked at the performance of a metallized plastic BWO, over shorter pulse durations [2].

The two anodes were printed from Water Shed XC 11122 photopolymer using a stereolithography process (Figure 1a). The first anode, RPM-12b, was then coated with an electrically conductive epoxy and electroplated with a ~0.1 mm layer of copper, for a finished mass of 5.09 kg. The other anode, RPM-12c, was thermally sprayed with a ~0.25 mm layer of copper (Figure 1b), for a finished mass of 5.24 kg. The baseline structure for comparison, RPM-12a, is 9.4 kg of solid aluminum. All three anodes were fabricated as 4 pieces and then bolted together for testing.

Experimental Setup

The Michigan Electron Long Beam Accelerator with a ceramic insulator stack (MELBA-C) was the driver for the RPM experiments, providing voltages between -250 and -300 kV for pulselengths of 200-600 us. A pair of pulsed electromagnets in a pseudo-Helmholtz configuration create a nearly uniform axial magnetic field, which was varied on a per-shot basis from 0.13 to 0.31 T. The magnetron was operated at base vacuum pressures on the low 10^{-6} torr scale, and individual gas components were monitored with a SRS RGA-200 residual gas analyzer.

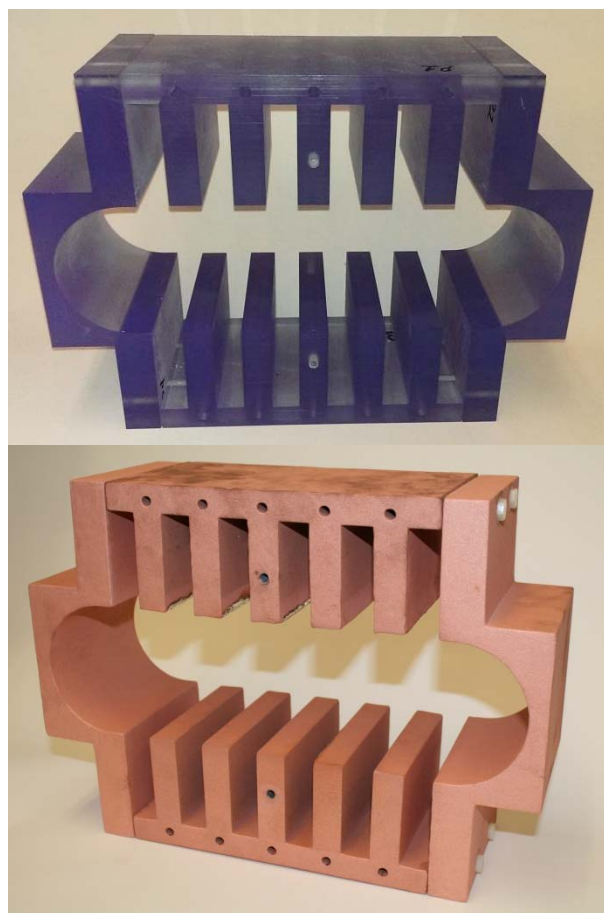

Figure 1. a) (Top) 3-D printed plastic anode prior to metallization. b) (Bottom) The same anode after thermal spraying.

Figure 2 shows the experimental configuration used for RPM-12a/b/c. Microwave power was extracted via two symmetric coaxial waveguides and was launched as a $TE_{1,0}$ mode in the waveguide by a coax-to-waveguide coupler (DFA-650b), to be sampled by a directional coupler (-58 dB), and then dissipated in an Ecosorb load. The sampled microwave signals were attenuated and then split using a 3 dB power divider, allowing us to both directly capture time-dependent frequency information and make calibrated power measurements with Schottky diode microwave detectors. Due to the axial extraction system, an endloss current measurement is not feasible. Estimates of endloss were obtained using a modified setup with no extraction system.

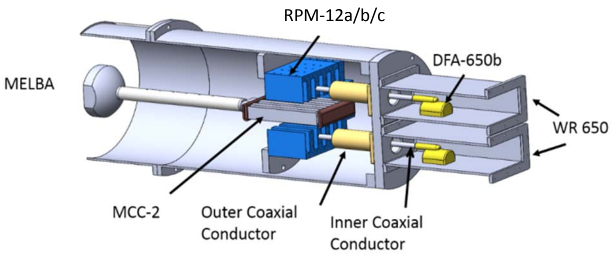

Figure 2. Experimental configuration for RPM-12a/b/c experiments. Anode region shown in blue, directional couplers and loads not shown.

Results

Magnetic Field Penetration: As the initial step of these experiments, we optimized the magnetic field diffusion time. Given our pulsed electromagnets, and the asymmetric anode structures used in the RPM, the field penetration time (to peak field) varies for each anode material, as well as across the cavities.

The 3-D printed anodes both exhibited faster diffusion and higher peak fields within the cavity. For our maximum magnet current of 1 kA, the peak field for the RPM-12a was only 0.21 T, while for the RPM-12b/c it was 0.28 and 0.30, respectively. This allowed us to explore a larger parameter space for the 3-D printed RPMs.

Microwave Performance: The 3-D printed anodes performed comparably to the solid aluminum anode in both peak power and instantaneous peak efficiency, as shown in Table 1. Typical RPM data are presented in Figure 3. When comparing the structures, we considered only data where the magnetic field was between 0.15-0.21 T, as this was the optimum operating range. The performance decreased for the higher magnetic fields, which the RPM-12a was unable to achieve.

Outgassing and Durability: To monitor outgassing, we tracked the partial pressure of CO_2 as a function of time, noting the pressure increase immediately after the shot. For the majority of shots, the pressure increase was roughly 1×10^{-5} torr for all three structures. However, the pressure would occasionally increase dramatically, saturating the RGA at 1×10^{-3} torr. This occurred more frequently for the 3-D printed anodes.

The RPM-12b & c were each subjected to 100 shots, with voltage and current pulses similar to Figure 3. No damaged was observed (beyond the imperfections present from the coating process).

Table 1. RPM-12a/b/c microwave performance for shots with magnetic field between 0.15-0.21 T.

	RPM-12a	12b	12c
Peak Power [MW]	101 +/- 18	120 +/- 20	101 +/- 17
Efficiency [%]	20 +/- 6	30 +/- 12	34 +/- 10

Conclusion

Recent UM experiments on the RPM have investigated 3-D printed anodes metallized via electroplating and thermal spraying. Both manufacturing processes were compared against a machined aluminum anode, demonstrating improvements in pulsed magnetic field penetration, while maintaining similar microwave performance. Outgassing was comparable, with a higher incidence of gas spikes for the plastic anodes. Over a limited set of shots, no damage or degradation was observed. Additional durability studies are planned.

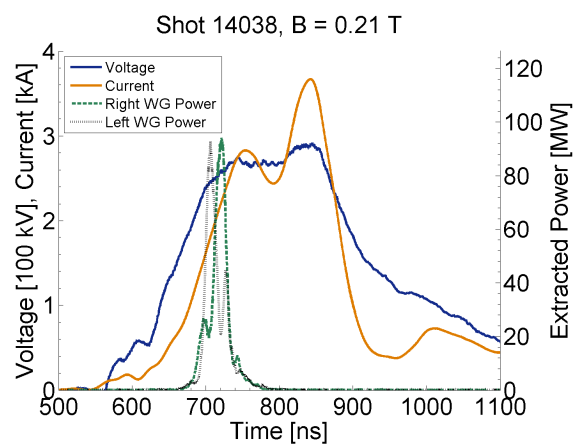

Figure 3. Sample shot from RPM-12b (electroplated).

Acknowledgements

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References

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