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Additive Manufacturing of a High Field Side Tokamak Lower Hybrid Current Drive Launcher from GRCop-84

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We present a High Field Side (HFS) Lower Hybrid Current Drive (LHCD) launcher for DIII-D (1) to validate HFS launch scenarios, Figure 1 (a), incorporating a novel traveling-wave power divider and aperture impedance matching structure for good coupling over a wide range of edge density conditions, produced with additive manufacturing from Glen Research Copper 84 (GRCop-84) a high strength, high conductivity copper alloy with resistance to swelling at high DPA. HFS LHCD is a key enabling technology for a steady state tokamak reactor, where inward particle drifts reduce plasma-material interaction (PMI) for launcher longevity, while the favorable magnetic profile allows lower n|| resulting in higher efficiency current drive with single-pass damping at increased penetration depth. No emission of molybdenum lines from the plasma core were detected under any operating condition or direct NBI strikes with a molybdenum HFS grill mockup, (b), and no post-run damage to the molybdenum grill mockup was observed.

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Electric field is reduced below the multipactor arcing threshold of 9.3 kV/cm by a traveling wave power divider, and an aperture impedance matching structure (2) within each launcher aperture. A thin inductive tuning element near the plasma surface tunes aperture impedance to match plasma surface impedance, resulting is low circulating power within the launcher, Figure 1 (c). The matching element allows tuning the region of lowest circulating power, simulated as |E|, (d), to match plasma conditions, estimated to be n0=3x1017 m-3 in a DIII-D advanced tokamak discharge. Simulations of an HFS multijunction launcher with aperture impedance matching in COMSOL, Petra-M, and ALOHA shows acceptable edge densities between ne=8x1016 to 1x1018 and return loss as low as -34 dB. GENRAY simulations show single pass damping of a 4.6 GHz LH wave at a n||=-2.7 launch at r/a=0.6-0.8 (e) with a current drive efficiency of 140 kA/MW.

Selective laser melting (SLM) 3D printing allows rapid construction of RF launcher structures at full density without a subsequent hot isostatic pressing step to achieve vacuum compatibility, Figure 2 (a), in configurations not possible with conventional machining out of materials with superior mechanical properties. SLM printed GRCop-84 has a UTS of 720 MPa, increasing to 780 MPa after a 600℃ stress relief and 2 hour heat treat at 450℃, exceeding CuCrZr (560 MPa) and Glidcop AL-15 (460 MPa), allowing better tolerance of disruption loads while tolerance of high temperature excursions to 800℃ for extended durations without loss of strength allows exposure to transient heat loads that cause permanent degradation to CuCrZr. Stability of the Cr2Nb precipitates results in modest reduction in tensile strength to 520 MPa after a 5 hour exposure to 900℃ (d).

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Brazing, laser, and electron beam welding of GRCop-84 produce favorable joining results (3). Brazing of GRCop-84 is similar to CuCrZr (e), and direct brazing to TZM limiters with active brazing alloys is possible. Launcher components are assembled (b) with laser or e-beam welding processes; precipitate structure is maintained during pulsed laser and electron beam welding (f). GRCop-84 laser welds exceptionally well due to higher absorption of 1060 nm wavelength in comparison to OFC.

Surface roughness that dominates RF loss in SLM printed GRCop-84 waveguide is addressed with mass finishing and polishing (c). As printed roughness of Ra=3.4 µm is reduced to Ra=0.025 µm when polished with 6 µm diamond. Chemo-mechanical polishing reduces surface roughness to Ra=0.17 µm and can reach interior surfaces that are not physically accessible to mechanical polishing allowing launchers to be printed as a monolithic unit.

Grain and precipitate size in SLM printed GRCop-84 is similar to existing alloys with low swelling and reduction in conductivity (CuCrZr, Glidcop, MZC) at high DPA predicts good tolerance to neutron exposure. Irradiation with 5 MeV Cu ions to 20 DPA at 430℃ results in no observable void formation at the deposition location (g). Transient Gradient (TG) spectroscopy provides measurement of thermal conductivity of as-printed and irradiated material.

Development of SLM 3D printing of GRCop-84 for fusion power applications is an emerging technology with the capability to improve LHCD launcher designs and may be extended to first wall, divertor, and RF source components.

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(1) Seltzman, A. H., et al. "A high field side multijunction launcher with aperture impedance matching for lower hybrid current drive in DIII-D advanced tokamak plasmas." Nuclear Fusion 59.9 (2019): 096003.
(2) Seltzman, A. H., et al. "Aperture Impedance Matching for Lower Hybrid Current Drive Launchers"Proc. of the 2019 RFPPC
(3) Seltzman, A. H., Wukitch, S. J. "Brazing, Laser and Electron Beam Welding of Additively Manufactured GRCop-84 Copper for Phased Array Lower Hybrid Launchers"IEEE Transactions on Plasma Science, (2019) https://doi.org/10.1109/TPS.2019.2963638

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