3-ELECTRODE RING OF FIRE® PLASMA SPLICING FOR HIGH-POWER FIBER LASERS

Independent validation from the University of Southampton Optoelectronics Research Centre

Source. Scarnera, V. (2020). *Advanced Techniques of Characterisation for High Power Fibre Lasers and Amplifiers*. Doctoral thesis, University of Southampton, Faculty of Physical Sciences and Engineering, Optoelectronics Research Centre. DOI: 10.5258/SOTON/D1215. Research sponsored by SPI Lasers Ltd. (acquired by TRUMPF in 2019).

Link to Full Study →

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Key Takeaways

- **Independent validation.** A University of Southampton doctoral thesis (Scarnera 2020), sponsored by SPI Lasers, compared 3-electrode Ring of Fire® and 2-electrode arc splicing head-to-head on the same fibers.
- **Symmetric by architecture.** The 3-electrode splice produces a centrosymmetric refractive-index profile; the 2-electrode does not (Sec. 3.3.4).
- **Stable under re-arcing.** 3-electrode LP11 holds across repeated re-arcs, where the 2-electrode degrades monotonically (Sec. 3.3.1, 3.3.4).

- **Better finished lasers**. FITEL-spliced laser builds show higher slope efficiency, lower mode-stripper grid temperature, and tighter repeatability (Sec. 5.5).
- **Available today.** The validated architecture ships in 3SAE's flagship lineup, including the FITEL S185.

Executive Summary

A 220-page doctoral thesis from the University of Southampton Optoelectronics Research Centre, completed under industrial sponsorship by SPI Lasers, has independently validated what 3SAE Technologies has built its splicing platform around for two decades. The 3-electrode Ring of Fire® plasma architecture measurably outperforms 2-electrode arc splicing on the metrics that matter for specialty fusion splicing: symmetry, repeatability, and process stability.

The study is the first long-form academic work to compare both architectures head-to-head on the same fibers, using refractive-index profilometry and S2 modal analysis at the splice. Its conclusion, reached after years of factory-floor measurement at SPI, is in the thesis abstract: "The optimal splice discovered in this work is now adopted in the mass production cycle of lasers at SPI Lasers" (Scarnera 2020, Abstract). The splicing architecture used to deliver that optimal splice is the 3-electrode Ring of Fire®.

Three findings drive that conclusion. First, the optimal splice between single-mode and few-mode fibers requires a precisely controlled higher-order-mode dose, deliverable only by a uniformly symmetric heat source. Second, the 3-electrode Ring of Fire® architecture produces a centrosymmetric refractive-index profile at the splice. The 2-electrode does not. Third, that symmetry holds through repeated re-arcing, where 2-electrode performance degrades monotonically. At the device level, those gains carry through to finished lasers: higher slope efficiency, lower mode-stripper grid temperature, and tighter build-to-build repeatability.

For OEMs evaluating specialty splicing capital, the implication is direct. The architecture validated by the Scarnera thesis is the same architecture available today in 3SAE's flagship splicing products, including the FITEL S185.

Why Splicing Architecture Matters for Specialty Fiber Processing

Specialty fiber processing depends on splices between dissimilar fibers. Single-mode passive and large-mode-area active. Doped to undoped. Large-cladding pump fiber to gain fiber. Each splice is a controlled diffusion event. Heat softens the glass, dopants migrate, and the refractive-index profile reshapes. The quality of that reshape determines how cleanly the fundamental mode of the receiving fiber is excited, and how much power leaks into lossy higher-order modes.

Traditional fusion splicers use two electrodes. Accelerated plasma streams from one side of the fiber to the other, depositing heat asymmetrically. The Scarnera thesis is explicit on the mechanism. Even with perfect mechanical alignment, "the plasma particles will pass either from one side or from the other of the fiber, resulting in an asymmetric supply of heat" (Scarnera 2020, Sec. 3.3.4). Over the molten zone, asymmetric heat means asymmetric diffusion. Asymmetric diffusion means a non-centrosymmetric refractive-index profile at the splice.

The penalty scales with fiber size:

- Telecom-grade fiber (6 µm core, 125 µm cladding): the asymmetry rarely matters.
- Specialty active fiber (24 µm core, 200 µm cladding): it matters enormously.
- Pump-combiner fiber (250 µm cladding, plus end caps and tapered components): the penalty is largest.

The bigger the fiber, the larger the area the splicer has to heat uniformly, and the more pronounced the 2-electrode asymmetry becomes.

This is the engineering reason 3SAE developed the Ring of Fire® architecture. Three electrodes driven by three-phase current produce a triangular plasma discharge that surrounds the fiber rather than streaming across it. The fiber receives heat from the radiation of recombining plasma, not from particle collision. The thermal profile is circumferentially uniform by design. The Scarnera thesis is the first academic study to measure the consequences of that design choice at the splice level: index profile, modal excitation, and splice repeatability.

Three Findings That Matter

The optimal splice exists, and it is counterintuitive. Conventional thinking holds that the cleanest splice is the one that excites zero higher-order modes. Scarnera shows otherwise. By varying arc duration on the same single-mode-to-few-mode fiber pair, the experiment identifies a clear minimum in LP02 excitation at a specific heat dose (Scarnera 2020, Sec. 3.3.1, Figs. 51 and 52). Below that dose, the splice is under-diffused. Above it, over-diffused. Both states couple more power away from LP01. The minimum corresponds to a small, controlled LP02 contribution that maps onto a maximum for the fundamental mode. This was the experimental discovery that drove the rest of the splicing work, and it has remained the optimisation criterion used in mass production at SPI.

Three electrodes produce a symmetric index profile. Section 3.3.4 puts the two architectures head-to-head on the same fiber with discharges of comparable energy, then measures the 2D refractive-index profile 50 µm downstream of each splice using an IFA-100 profiler. The result is direct: “the index of refraction obtained with the ROF splicer is more symmetrical than obtained with the two electrodes splicer” (Scarnera 2020, Sec. 3.3.4, Fig. 64). The 2-electrode profile shows asymmetry traceable to the unidirectional plasma flow; the 3-electrode profile is centrosymmetric.

Re-arcing degrades 2-electrode splices. 3-electrode splices hold. Re-arcing is a common production step used to optimize modal content after the initial joining arc. On a 2-electrode splicer, LP11 excitation grows monotonically with re-arc count (Scarnera 2020, Sec. 3.3.1, Fig. 55). The asymmetric heat compounds with each pulse. On the same fibers with a 3-electrode splicer, LP11 holds at the value it had after the initial joining arc across multiple re-arcs (Scarnera 2020, Sec. 3.3.4, Fig. 68). For process engineers, this is the difference between a process window of one arc and a process window of ten.

What This Means for Specialty Fibre OEMs

The Scarnera thesis answers a question every production engineer running specialty splices has had to wrestle with quietly. Why are some splices on the floor consistently better than others, when the recipe is identical? The answer, validated by direct measurement at the index and modal levels, is that 2-electrode splicing has an intrinsic noise floor set by the unidirectional plasma flow. That noise floor cannot be tuned out with recipe optimization. It is an architectural property of the equipment.

The thesis is equally direct on the practical consequences. “We have always adopted the FITEL splicer and splice optimisation with arc characterisation” (Scarnera 2020, Sec. 5.5), referring to the period since SPI began producing large-mode-area lasers. That decision is not stated as a vendor preference. It is the conclusion of repeated factory-floor measurement across multiple fiber generations. SPI was acquired by TRUMPF in 2019, and the same splicing architecture remains in mass production.

The thesis measured the payoff of that decision directly. A single laser built four times on a 3-electrode FITEL splicer and four times on a 2-electrode FUJIKURA splicer showed the FITEL builds clustering at higher slope efficiency and lower mode-stripper grid temperature, with “much more repeatable” results; the FUJIKURA builds scattered (Scarnera 2020, Sec. 5.5, Fig. 137). Across mass-produced lasers the same inverse correlation held: the better the splice, the higher the efficiency and the lower the higher-order-mode activity, with an asymptotic efficiency ceiling of roughly 74–82% at the limit of perfect splices (Scarnera 2020, Figs. 137 and 138).

For OEMs evaluating specialty splicing capital, three observations follow.

The performance gap between 3-electrode and 2-electrode splicing widens as fiber diameter grows.

For pump-combiner fibers at 250 µm cladding, for active fibers at 200 µm cladding, for end caps and tapered components, the symmetry advantage is not a marginal preference. It is a process-critical capability.

The gap holds through process iteration.

Re-arc cycles, recipe adjustments, and operator variability all stress the splicer. The 3-electrode Ring of Fire® architecture absorbs that stress without LP11 degradation. The 2-electrode does not. For production lines that require operator-independent repeatability across shifts and batches, this is the deciding factor.

The same Ring of Fire® heat source measured by Scarnera is available today in the 3SAE flagship product lineup.

The architecture is not legacy hardware. It is the current production standard at the world's largest industrial fiber laser manufacturer, and it is the same architecture 3SAE delivers to OEMs evaluating new capital today.

3SAE Flagship Splicing Technology

3SAE Technologies and Furukawa are the dominant global suppliers of 3-electrode Ring of Fire® plasma fiber processing equipment. The architecture validated by the Scarnera thesis is available today in the 3SAE flagship glass processing splicing product line, including the FITEL S185 specialty fusion splicer.

FITEL S185 Specialty Fusion Splicer

The direct successor to the splicer family Scarnera tested at SPI. The S185 combines a 3-electrode Ring of Fire® arc with the compact FITEL S185 platform, supporting specialty fibers up to 800 μm cladding diameter. It is built for production environments that handle polarization-maintaining, multi-core, and hollow-core specialty fibers, and it is the splicer 3SAE recommends for OEMs running large-mode-area active fibers on a production floor.

Ring of Fire® Wide Area Plasma Technology

The 3-electrode plasma source that delivers the symmetry and repeatability characteristics documented in the Scarnera thesis is 3SAE's patented Ring of Fire® Wide Area Plasma Technology. The three-phase arc encircles the fiber uniformly rather than streaming across it, expanding the heat zone to accommodate fibers greater than 1 millimeter in diameter, which is twice the working range of a standard 2-electrode fusion splicer. The technology is available across the 3SAE glass processing product line and is also available in the FITEL fusion splicer platform via a technology partnership with 3SAE.

Request a Quote from a 3SAE Engineer

The full Scarnera thesis is publicly accessible at DOI 10.5258/SOTON/D1215 and is available for OEMs that want to review the primary research before evaluating capital.

For manufacturers evaluating specialty splicing platforms, the fastest path is a direct conversation with a 3SAE engineer about your fiber geometry, throughput target, and production constraints.

Request a Quote →

About This Brief

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