



## Techniques for Connecting Superconducting Thin Films

Junctions can be tailored to obtain desired levels of electrical resistance.

*Marshall Space Flight Center, Alabama*

Several improved techniques for connecting superconducting thin films on substrates have been developed. The techniques afford some versatility for tailoring the electronic and mechanical characteristics of junctions between superconductors in experimental electronic devices. The techniques are particularly useful for making superconducting or alternatively normally conductive junctions (e.g., Josephson junctions) between patterned superconducting thin films in order to exploit electron quantum-tunneling effects.

The techniques are applicable to both low- $T_c$  and high- $T_c$  superconductors (where  $T_c$  represents the superconducting-transition temperature of a given material), offering different advantages for each. Most low- $T_c$  superconductors are metallic, and heretofore, connections among them have been made by spot welding. Most high- $T_c$  superconductors are nonmetallic and cannot be spot welded. These techniques offer alternatives to spot welding of most low- $T_c$  superconductors and additional solutions to problems of connecting most high- $T_c$  superconductors.

A superconducting thin film can be formed on a flat substrate. When two such substrate-supported thin films are placed face-to-face in tight contact by any means, electrical conductivity can be established across the resulting interface or junction between them. If the electrical

resistance of the junction can be made relatively low, then the junction can serve as an ordinary electrical connection between the superconductors. On the other hand, provided that the junction can be tailored to impart a specified larger electrical resistance, the junction can be used to create desired electron quantum-tunneling effects. Such a thin-film-to-thin-film contact can be formed in one of three ways:

1. Bonding the two substrates together,
2. Mechanically fastening the two substrates together, or
3. Bonding the two thin films together, with or without bonding and/or mechanically fastening of the two substrates.

In general, one would bond the substrates to obtain reliability better than could be obtained by mechanical fastening of the substrates. On the other hand, mechanical fastening of the substrates offers the advantage of reversibility of the connection between the superconducting thin films.

For the purpose of the present innovation, the bonding of substrates and superconducting films can be effected by any of the established techniques generally used for that purpose in the art of superconducting thin films. In particular, the hydroxide catalyzed optical bonding process developed for NASA's Gravity Probe B mission is well-suited for the controlled bonding of superconductors.

Prior to making a junction in one of the three ways described above, the electrical resistance of the junction can be modified in one of the following ways, depending on the specific application:

- Generally, the electrical resistance of the junction can be increased by creating an electrically resistive layer on either or both superconducting thin films to be bonded.
- In the case of metallic superconducting thin films with surface oxide layers, the electrical resistance of the junction can be reduced by etching, scratching, or polishing to thin or remove the oxide layers. In one variant of this approach, the two thin films can simply be scratched against each other while the electrical resistance is monitored in real time to prevent excessive thinning of the oxide.
- If the two superconducting thin films are to be directly bonded, the electrical resistance of the junction can be increased in a controlled manner via the resistance of a bonding material. Optionally, beads of a known electrical resistivity and known size distribution can be added to the bonding material to control the thickness of the bonding interfacial layer and thereby obtain the desired electrical resistance.

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## Versatile Friction Stir Welding/Friction Plug Welding System

A single system could perform any FSW or FPW operation.

*Marshall Space Flight Center, Alabama*

A proposed system of tooling, machinery, and control equipment would be capable of performing any of several friction stir welding (FSW) and friction plug welding (FPW) operations. These operations would include the following:

- Basic FSW;
- FSW with automated manipulation

of the length of the pin tool in real time [the so-called auto-adjustable pin-tool (APT) capability];

- Self-reacting FSW (SRFSW);
- SR-FSW with APT capability and/or real-time adjustment of the distance between the front and back shoulders; and

- Friction plug welding (FPW) [more specifically, friction push plug welding] or friction pull plug welding (FPPW) to close out the keyhole of, or to repair, an FSW or SR-FSW weld.

Prior FSW and FPW systems have been capable of performing one or