Ultra High Density Wiring

Flexible superconducting transmission lines for cryogenic applications

Thin, flexible RF transmission lines for superconducting quantum circuits fabricated at Fraunhofer EMFT using roll-to-roll technology to enable upscaling of parallel interconnects (1000+) in the cryostat. ©Fraunhofer EMFT/ Bernd Müller

Demand

Compared to the current state of the art, large scale quantum processors require a much larger number of transmission lines for signal processing than conventional computer systems. The advantage of flexible interconnects over currently used solutions within quantum computers like coaxial cables is the ability to increase interconnect densities. At the same time thermal loads can be significantly mitigated by decreasing the total cable cross section and thus the total thermal mass per interconnect.

Innovation

New technical solutions are now being offered by roll-to-roll manufacturing concepts. Polymeric films are used as base substrates for superconducting wiring systems.

1.25 m long transmission lines with a width and spacing down to 20 µm are fabricated on polyimide foil by digital photolithography and wet chemical etching of the copper. By lithographically stitching consecutive images of 10 cm long line segments, copper lines of any length can be generated. ©Fraunhofer EMFT/Bernd Müller

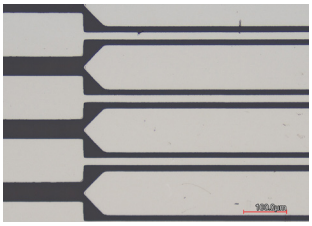
Polymer film materials like polyimide may be procured as rolls with lengths of five hundred meters and thereby offer a unique solution for the production of several meter-long electronic systems.

The key innovative solution here is based on direct write lithography systems: instead of using photomasks and full area UV exposure of the photoresist, a micrometer fine UV light beam (coming from laser or LED optics) is precisely scanned over the resist and "writes" the desired pattern into the resist layer.

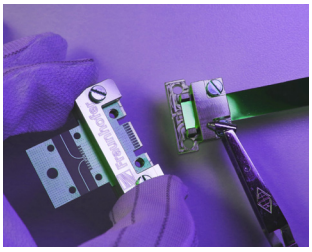
One of the unique advantages of film-based electronics is the extremely thin form factor. The cables have a total thickness of less than 100 micrometers. The small cross-section allow the cables to be flexibly accommodated in the available space inside the quantum computer cryostat. Another advantage that arises from this is that significantly less heat is passively transferred. Therefore, the Fraunhofer high density wiring system can contribute to optimal utilization of limited cryostat capacities.

Fraunhofer's Superconducting High Density Wiring Solution

First demonstrators of superconducting flexible cables for cryogenic applications were implemented by Fraunhofer EMFT and Fraunhofer IIS:



a)



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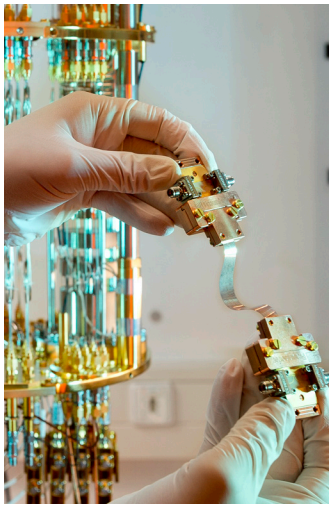

c)

a) Conductor structures made of niobium on a polyimide substrate
b) Superconducting interconnection of 10 signal lines via face-to-face transition
c) Measurements under cryogenic conditions in the Fraunhofer laboratory

The images show examples of superconducting flexible cables for cryogenic applications. The production process allows for the precise manufacturing of highly integrated cables. Thanks to a shielding concept that surrounds each transmission line with a via-fence, crosstalk can be minimized over the length of the cable.
A direct contact system makes it easy to mount superconducting cables onto printed circuit boards. Optical and mechanical alignment structures are used to achieve optimum contact even with very small pitches.

Technical data

The design of the cables makes it possible to provide a large number of signal lines in a very small space. Signal integrity in terms of cross talk and signal losses is ensured by the use of superconducting materials and the innovative shielding concept. Furthermore, Fraunhofer has developed additional specific functions such as bandpass/lowpass filters or attenuators that can be integrated directly into the cable.
The cable design is highly scalable and can therefore be adapted to customer requirements at any time.
The characteristics of the developed cable solution are detailed in the table below.

Thin-Film Cable		
Length		as required
Thickness		< 0.1 mm
Transmission-line type		Stripline
Materials	Signal line	Nb
	Shielding	Nb
	Substrate	Polyimide
Connector		
Type		High Density Clamped Connection
Material		Cu-OF

Electrical Specification	
Impedance	50 Ω
Operating Frequency	DC to 10 GHz
Crosstalk	< -60 dB
Return Loss	< -20 dB
Attenuation (T < 7 Kelvin)	<< 2 dB /m

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