Perspective on Basic Architectures and Properties of Unconventional and Field Induced Josephson Junction Devices

Krzysztof Pomorski*†, and Przemyslaw Prokopow†‡

***Abstract*—We present the concept of unconventional and Field Induced Josephson junction (uJJ and FIJJ) and devices built from them. They can be made by placement of ferromagnetic strip on top of a superconducting strip. In such case modulation of superconducting order parameter and magnetization is obtained. Furthermore we can build tunable Josephson junction arrays, which can be tuned by applying external magnetic field to some circuit element(s). We present the superconducting order parameter distributions obtained from extended Ginzburg-Landau functional, which includes the coexistence of superconducting order parameter and magnetization. We present the case of SQUID built in uJJ and FIJJ architecture and current limiter.**

***Index Terms*—uJJ and FIJJ Josephson junction arrays and matrices, uJJ and FIJJ fault current limiter, various geometries of uJJ and FIJJ, uJJ and FIJJ SQUID, relaxation algorithm**

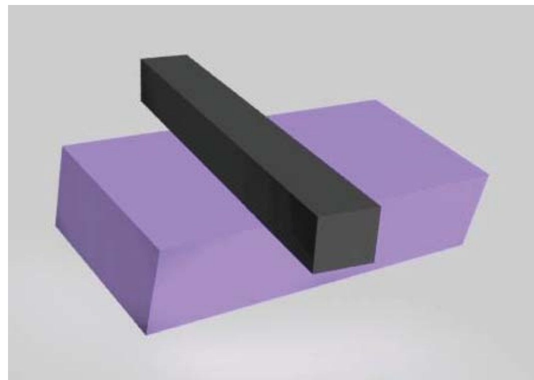

Fig. 1. The placement of nonsuperconducting or ferromagnetic strip on the top of superconducting strip as the concept of unconventional Josephson junction or Field Induced Josephson junction (FIJJ).

I. Motivation to Study uJJ and FIJJ Structures

JOSEPHSON junctions can be used for information processing and as detectors of magnetic and electromagnetic field and as emitters of electromagnetic radiation. In particular the superconducting processor can be built with same operations on bits as currently known processors but with energy use of five orders of magnitude smaller than conventional processors. The idea of a Josephson junction was firstly presented by Josephson [8] and assumes non-perturbative interaction of two superconductors by narrow link. Tunneling Josephson junctions are well studied theoretically while weak-link Josephson junctions are more difficult to analyze and still need to be studied. For a summary of weak link Josephson junctions see Likharev work [6].

We define the structure made by putting the nonsuperconducting or ferromagnetic or ferroelectric strip on the top of superconductor as unconventional Josephson junction (uJJ) and Field Induced Josephson junction (FIJJ) as depicted in Fig. 1. We prove the possible occurrence of Josephson effect in such structures in [1], [3]. The experimental prove is given by [4]. We define the unconventional Josephson junction as the case of FIJJ structure with non-superconducting and non-ferromagnetic strip on the top of superconductor strip. In order to establish the transport properties of the structure we have to solve the Ginzburg-Landau equations at first. Cooper pairs are diffusing from the superconductor to the nonsuperconductor which lowers the magnitude of the superconducting order parameter. Also diffusion of normal electrons from nonsuperconductor to superconductor lowers the superconducting order parameter in superconductor. In addition the magnetic field or magnetization can be used to diminish the superconducting state.

Various cases of uJJ and FIJJ device architectures is given. Its description is given by Ginzburg-Landau equations which are numerically solved with the relaxation method. Distributions of superconducting order parameter is given by examples. Brief technical evaluation of uJJs and FIJJs is given.

II. Mathematical Description of uJJ and FIJJ Devices

In order to give a description of a system ferromagnetic or non-ferromagnetic strip on the top of superconductor strip we use Ginzburg-Landau formalism. In the case of s-wave superconductor-ferromagnet system the free energy functional is of the form

$$F = F_{sc} + F_M + F_{sc-M} \quad (1)$$

including the term responsible for the description of the ferromagnetic state

$$F_M = \int dr(a(T)|M(r)|^2 + \frac{b(T)}{2}|M(r)|^4 + C|\nabla M(r)|^2), \quad (2)$$

the term resonsible for the superconducting state

$$F_{sc} = \alpha|\psi|^2 + \beta|\psi|^4 + \sum_k \frac{1}{2m}|(\frac{\hbar}{i}\frac{d}{dx_k} - \frac{2e}{c}A_k)\psi|^2 + \frac{(rot A)^2}{4\pi}, \quad (3)$$

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and the term describing the interaction of the superconducting state with ferromagnetic bar

$$F_{sc-M} = \int dr(\frac{\mu}{2m}|(\frac{\hbar}{i}\nabla - \frac{2e}{c}A)\psi(r)|^2(|M(r)|^2)) \\ +\gamma|\psi(r)|^2|M(r)|^2 + \epsilon(|\nabla M(r)|^2|\psi(r)|^2) + rot(A)M, \tag{4}$$

where $a(T)$, $b(T)$, C, α, β, γ, μ, ϵ are constans that can be derived from a microscopic theory as done by Kuboki [2].

The free components of free energy functional describe the ferromagnet, superconductor and interaction between superconductor and ferromagnet. Such approach is valid when the superconductor is close to critical temperature T_c. The occurence of Sc-N interface (superconductor-nonsuperconductor) is expressed by boundary condition: $\underline{n}\Pi\psi(x) = \underline{n}(\frac{\hbar}{i}\nabla - \frac{2e}{c}A(x))\psi(x) = \frac{1}{b}\psi(x)$, where b is the constant depending on material and $\underline{n}$ is the normalized vector perpendicular to the surface of interface. In the case of the d-wave superconductor the usage of GL $(x^2 - y^2)$ model is necessary and the free-energy functional of superconductor is of the form

$$F_d = \alpha_s|\psi_s|^2 + \alpha_d|\psi_d|^2 + \beta_d|\psi_d|^4 + \gamma_s|\psi_s|^2\gamma_d|\psi_d|^2 \\ +\beta_{sd}(\psi_s^{\dagger 2}\psi_d^2 + \psi_d^{\dagger 2}\psi_s^2) + \beta_{sd'}|\psi_s|^2|\psi_d|^2 \\ +\gamma_{sd}((\pi_y\psi_s)^\dagger(\pi_y\psi_d) - (\pi_x\psi_s)^\dagger(\pi_x\psi_d) + h.c.) + \frac{rot(A)^2}{8\pi}, \tag{5}$$

Here α_s, α_d, β_d, γ_s, β_{sd}, $\beta_{sd'}$, γ_{sd} are constans that can be derived from microscopicture.

The superconducting order parameter is expressed as the linear combination of s and d wave component as

$$\Delta(x,y,z) = \psi_s(x,y,z) + cos(2\phi)\psi_d(x,y,z) \tag{6}$$

Here ϕ is the angle in ab plane set in the way that d wave component vanish in certain direction. In such case of occurrence of Sc-N (superconductor-normal metal) interface is accounted for by the following boundary condition

$$\frac{i}{\kappa}\underline{n}(\Pi\psi_s + \frac{1}{2}(\Pi_x - \Pi_y)\psi_d) = -V_s(\psi_s), \\ \frac{i}{\kappa}\underline{n}(\Pi\psi_d + (\Pi_x - \Pi_y)\psi_s) = -V_d(\psi_d) \tag{7}$$

Here V_s and V_d depend on the material constants. The Δ is the global superconducting order parameter as obtained from two order parameters and $\kappa = \frac{\lambda}{\xi}$ is the ration between magnetic field penetration depth and superconducting coherence lenght and $\Pi = \frac{\hbar}{i}(\Pi_{ab} + \eta\Pi_c) - \frac{2e}{\hbar c}(A_{ab} + \eta A_c)$ and $\Pi_{ab} = \underline{i}\nabla_x + \underline{j}\nabla_y$, $A_{ab} = \underline{i}A_x + \underline{j}A_y$,$A_c = A_z\underline{z}$, $\Pi_c = \nabla_z$, η-parameter accounting electron effective mass anisotropy, $\Pi_x = \frac{\hbar}{i}\nabla_x - \frac{2e}{\hbar c}A_x$,$\Pi_y = \frac{\hbar}{i}\nabla_y - \frac{2e}{\hbar c}A_y$.

III. Description of Numerical Method

Solving the GL equations for any type superconductor (e.g. with s or d-wave symmetry) describing the FIJJ structures in all cases is currently beyond the scope of current research. However to establish basic FIJJ structure properties it seems to be enough sufficient to solve GL equations in numerical way. When the final solution of GL equation is obtained then $(\frac{\delta}{\delta\psi}, \frac{\delta}{\delta A}, \frac{\delta}{\delta M})F[\psi, A, M] = 0$. In numerical case this condition is approximated, while in analytical case it is strictly fulfilled. One of the numerical method that can be used is the relaxation method as described by [14]. At first we make intuitive guess of physical fields to be computed. Then we apply the scheme:

$$\frac{\delta}{\delta X_i}F[\psi, A, M] = \eta_i\frac{\Delta X_i}{\Delta t}, X_i = (\psi, A, M) \tag{8}$$

where $i = 1, 2, 3$ and η_i is some constant and Δt is fixed. In some cases Δt can depend on the iteration step and should be set to become smaller if we approach the final solution. Here t is virtual time and is discrete by final number of iterations. When we approach the final solution the total free energy of the system becomes smaller and is saturating. In this work we solved the equations numerically with certain approximation for the case of time independent GL.

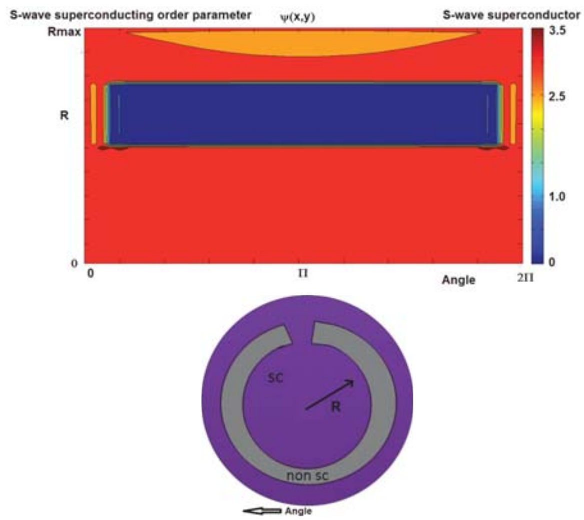

Fig. 2. Distribution of superconducting order parameter (SCOP) in cylindrical uJJ junction (case of Fig. 6g)

The obtained numerical results describe the superconducting order parameter distribution (SCOP) in the case of superconducting structures consisting rectangular symmetric or asymmetric unconventional Josephson junction array (Fig. 3), d-wave current limiter with use of uJJs architecture (Fig. 5), cylindrical unconventional Josephson junction (Fig. 2).

In cases of s-wave superconductor the presence of vacuum or non-superconducting element results in lowering the magnitude of the superconducting order parameter which is intuitive and is reflected in numerical results as depicted in Figs. 3 – 6. However in the case of d-wave superconductor the presence of defects at first increases the magnitude of the s-wave order parameter and later it decreases, while it always brings the decrease of d-wave order parameter . Such situation can be understood on the example of vortex case in d-wave superconductor as described by Alvarez [15]. What is commonly known the rectangular, cylindrical and spherical geometry gives the following gradient structure $\nabla f = (\hat{x}\frac{d}{dx} + \hat{y}\frac{d}{dy} + \hat{z}\frac{d}{dz})f$, $\nabla f = (\hat{r}\frac{d}{dr} + \hat{\phi}\frac{1}{r}\frac{d}{d\phi} + \hat{z}\frac{d}{dz})f$ and $\nabla f = (\hat{r}\frac{d}{dr} + \frac{1}{r}\hat{\theta}\frac{d}{d\Theta} + \hat{\phi}\frac{1}{r\sin\Theta}\frac{d}{d\phi})f$, which has the obvious impact on final equations.

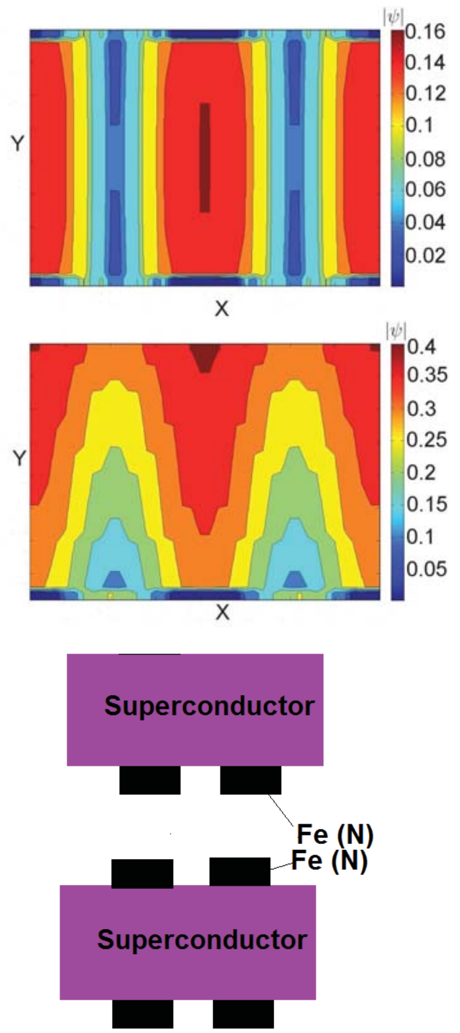

Fig. 3. Superconducting order parameter distribution in asymmetric and symmetric 2 FIJJ array in the rectangular geometry (FIJJ case of Fig 6b).

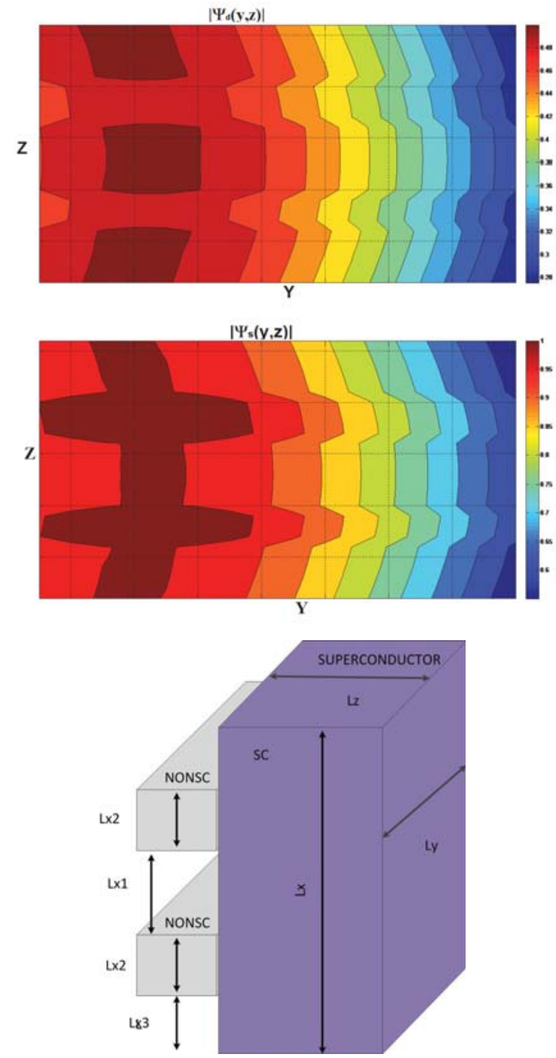

Fig. 4. 2-dimensional distribution of D and S wave superconducting order parameter in asymmetric D-wave uJJ array and view of the physical structure (case of Fig. 6b).

IV. Devices Built from uJJ and FIJJ Concept

Using the concept described by Clinton, Gomez, Maeda, Pomorski [1], [3], [4] it is possible to build FIJJ devices by putting the ferromagnetic strip on the top of superconducting strip. Many of the system properties depends on the quality of superconductor-nonsuperconductor or superconductor-ferromagnet interface. The central idea exploited in uJJ and FIJJ devices is that in the contact of superconductor with non-superconductor there is diffusion of paired electrons (Cooper pairs) from superconductor into non-superconductor. There is also diffusion of unpaired electrons from non-superconductor to the superconductor. Such phenomena lowers the magnitude of the superconducting order parameter inside superconductor. If one uses the ferromagnetic strip there is also diffusion of magnetization from ferromagnet into superconductor. It is reflected by the diffusion of spin polarized normal electrons and in the destruction of the singlet Cooper that can be broken by magnetic field.

We can use the concept of FIJJ or uJJ device using the rectangular, cylindrical or spherical geometry. In particular it is possible to construct the symmetric and asymmetric array of FIJJs and uJJs as given in Fig. 3. The non-linear SQUID and current limiter can be constructed with usage of FIJJ elements. The array of uJJs and FIJJs is relatively easy to be implemented from the technological point of view. It does not require sophisticated lithography techniques. The physical structures that can be implemented with use of FIJJ concept are specified in Fig. 6 and are listed in the table 1. In particular we can build the SQUID device using 2 ferromagnetic strips placed on the top of superconducting strip with the hole inside. Presence of the ferromagnetic element gives rise to a nonlinear response and makes the device more sensitive to the external magnetic field. Other useful configuration of FIJJ system is the d-wave current limiter with additional presence of ferromagnetic or nonferromagnetic strip close to narrowing as depicted in Fig. 6.

Determination of transport properties of uJJ and FIJJ devices is quite similar to the case of determination of uJJ and FIJJ transport properties. Using Bogoliubov-de-Gennes equations we can establish the effective reflection coefficient of the given structure in the limit of zero external electric current

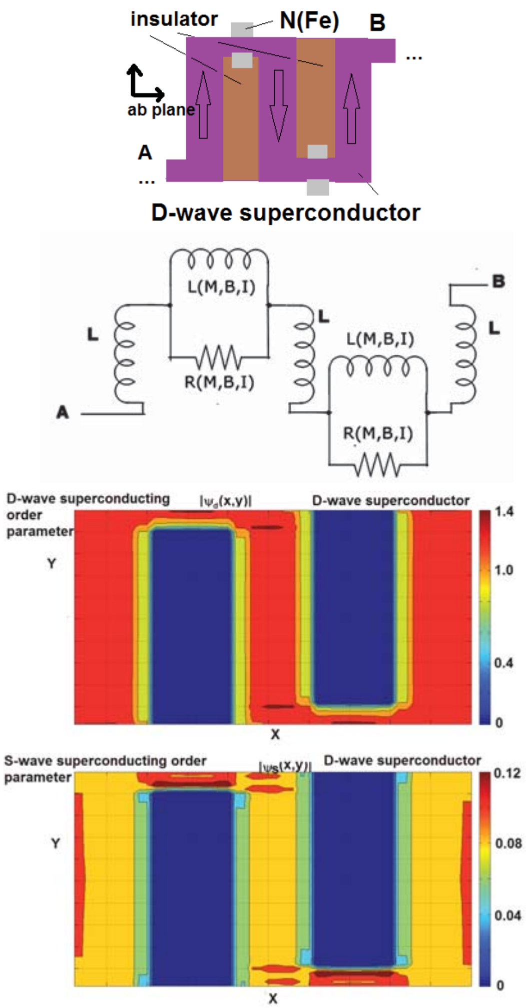

Fig. 5. Current limiter implemented in d-wave superconductor in ab plane.2 uJJ junctions are used in the narrowing places. The circuit representation is given. 2-dim distribution of d and s wave superconducting order parameter in D-wave current limiter is depicted (case of Fig. 6f).

flow. However if the external current flow is not small, the superconducting order parameter changes due to non-zero vector potential and magnetic field. There is also the coupling between FIJJ (uJJ) devices, which is usually perturbative. However this depends on the strength of magnetization of Fe bars and geometrical configuration.

The description of some device properties from Fig. 3 and Fig. 4 by means of time-dependent Ginzburg-Landau equation is done in [5], [11].

V. Various Aspects of Physical Properties of uJJ and FIJJ Devices

Vortex physics is more simple in uJJ than FIJJ devices. It becomes much more challenging if one considers the case of d-wave superconductor, because of its strong anisotropy. Then 3 types of vortices can occur in the system as Josephson, Abrikosov and pancake vortex. However for low concentration of vortices one can represent single vortex as particle with zero mass. Then the movement of the vortex is described by a set of forces as presented in [10]. There is a certain analogy of movement of vortices with movement of hard spheres in viscous media. Vortex attachment to Fe structure in FIJJ or possible movement and interaction with other vortices in such system is still an open issue. Nevertheless behavior of vortices is similar to behavior of particles in fluids. The problem becomes more pronounced if we have few interacting FIJJ devices by means of vortices.

Introduction of the granular structure to the superconductor in uJJ (FIJJ) makes the whole theoretical description much more easy. The neighboring granular structures can interact also via Josephson way. What is more this interaction can be represented by RCSJ (resistor shunted capacitor Josephson junction). Given the granular structure of superconductor and the distribution of the superconducting order parameter we can establish 2 dimensional network of RCSJ circuits.

VI. Summary of the Potential Applications of uJJ and FIJJ Devices

This work presents new architecture of unconventional and field induced Josephson junctions and gives example of numerical solution of the Ginzburg Landau equation for the specified cases. The application of ferromagnetic or nonsuperconducting strip on the top of superconducting strip allows to produce the Josephson junction in very rapid way which is technologically simple and can be made on massive scale. Therefore one can expect the FIJJ or uJJ Josephson junction devices and circuits to be implemented in the circuits of small and medium level of integration. One can build various detectors and devices as current limiter or electromagnetic antenna that can either receive or emit the electromagnetic radiation. The application of ferromagnetic element allows to have the controllable device within certain parameter range. If we use the nonsuperconducting and nonferromagnetic elements one can make the device, which has relatively simple physics as in comparison with the ferromagnetic case. In principle one can use the ferroelectric materials instead of ferromagnetic. Then the mathematical formalism describing the device is the same as in the case of ferromagnetic material. However the range of certain coefficients in Ginzburg-Landau functional is different. From the point of view of application the most attractive is the case of usage of d-wave superconductors since some of them can superconduct at the temperature of liquid nitrogen.

The effectiveness of emission or absorption of electromagnetic waves can be enhanced by using the second type superconductor placed in the external strong magnetic field. Then there occur the Abrikosov vortices. If we use the d-wave superconductor one can also observe the Josephson or panckace vortices, which have big vortex core and can be sensitive to external electromagnetic radiation. The core of vortices is in the quasi-normal state. The quasi-particles can absorb or emit the electromagnetic waves much more effectively than in the case of Cooper pairs.

Most devices presented here are uncoventional weak link Josephson junctions. Physical properties of such weak links are quite similar to the case of weak links studied by Likharev [6], [12]. If one uses the ferromagnetic strip then there is the possibility that the system could have transition from the weak-link behavior to the quasi-tunneling Josephson junction as presented by [3].

It should be emphasized that in the case when the superconductor thickness is sufficiently small and when the whole system is close to superconducting critical temperature one can linearize the Ginzburg-Landau equations. In such case they are of the type of Schrodinger or diffusion equation. In such case the numerical and analytical solutions of the equations for the postulated devices become much easier. Hence more physical parameters can be determined as direct current current-voltage characteristic. One can also use more advanced mathematical formalism as Bogoliubov de Gennes, Usadel, Eilenberger or Keldysh techniques. This is however the subject of future work.

One can think of dirty (with superconducting grains) unconventional or dirty field induced Josephson junction devices. In such case the vortex movement is by hopping, which occurs between the edges of superconducting grains. The vortices can be pinned down by nonsuperconducting or ferromagnetic strip. Vortices with cores in the plane of device would tend to move via the region of decreased superconducting order parameter.

One can think about applying the presented class of devices for the implementation of tunable superconducting qubit(s). However it should be pointed that weak link type Josephson junction is much less attractive for quantum information processing than tunneling Josephson junction. Current direction of superconducting qubit implementation is focused on usage of tunneling Josephson junction devices as pointed by F. Nori in [13].

This is because the superconducting order parameter strength in weak link region is usually much stronger than in the thin insulator in tunneling junction. This means that the defect in the superconducting order parameter is much smaller in weak-link than in other type of Josephson junction. Such situation implies that the distance between neighbouring energetic levels of quasiparticles is much smaller in weak-link system what is technical disadvantage for the qiven superconducting qubit implementation. Small distance between quasiparticles eigenergies in Josephson junction can make small decoherence time of qubit. Such situation can be changed if we place FIJJ device in strong external magnetic field that will diminish the superconducting order parameter in the region under the nonsuperconducting strip. Therefore one can think about novel superconducting qubit implementation in various geometries as presented in this work.

One should stress that the mentioned devices can be studied experimentally quite easily. The easiest geometry seems to be rectangular. More difficult is the cylindrical geometry while the spherical or toroidal geometries are the most difficult to obtain experimentally. Some work in this direction was done by L. Gomez [4], Clinton [7] and Reymond [9]. We look towards the possible experimental implementation of the studied devices. We believe that the studies of the given structures seem to bring the new results both to fundamental and applied science. Evaluation of technical use of various geometries of uJJ and FIJJ devices is presented in Table I.

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References

[1] K. Pomorski, P. Prokopow, "Towards the determination of properties of field induced Josephson junction made by putting ferromagnetic strip on the top of superconducting strip", Electronic Journal of Theoretical Physics 7 No. 23 (2010)
[2] K. Kuboki, "Microscopic derivation of the Ginzburg-Landau equations for coexistent states of superconductivity and magnetism", arXiv:1102.3329 (2011)
[3] K. Pomorski, "Possible existence of field induced Josephson junction", Physica Status Solidi B (2012)
[4] A. Maeda, L. Gomez, "Experimental Studies to Realize Josephson Junctions and Qubits in Cuprate and Fe-based Superconductors", Journal of Superconductivity and Novel Magnetism 23, (2010).
[5] K. Pomorski, P. Prokopow, "Numerical solutions of time-dependent Ginzburg-Landau equations for various superconducting structures", Recherches sur les d'eformations (2012)
[6] K.K. Likharev, "Superconducting weak links", Review of Modern Physics 51, (1979)
[7] T. Clinton, "Advances in the development of the magnetoquenched superconducting valve: Integrated control lines and a Nb-based device", Journal of Applied Physics 91 (2002)
[8] B.D. Josephson,"Possible new effects in superconductive tunnelling", Physics Letters 1 (1962)
[9] J.S. Reymond, P. SanGiorgio, "Tunneling density of states as a function of thickness in superconductor/strong ferromagnet bilayers", Physical Review B 73 (2006)
[10] X.B. Xu, H. Fanohr, "Vortex dynamics for low-k type superconductors", Physical Review B 84 (2011)
[11] K. Pomorski, P. Prokopow, "Numerical solutions of nearly time-dependent Ginzburg-Landau equations for various superconducting structures", Recherches sur les d'eformations, (2011)
[12] M. Thinkham, "Introduction to superconductivity", Dover Publications (2004)
[13] J.Q. You, F. Nori, "Superconducting Circuits and Quantum Information", Physics today (2005)
[14] N. Cassol-Seewald, G. Krein, "Numerical simulation of Ginzburg-Landau-Langevin equations", Brazilian Journal of Physics 37 (2007).
[15] J.J.V. Alvarez, C.A. Balseiro, "Vortex structure in d-wave superconductors", Physical Review B 58 (1998)

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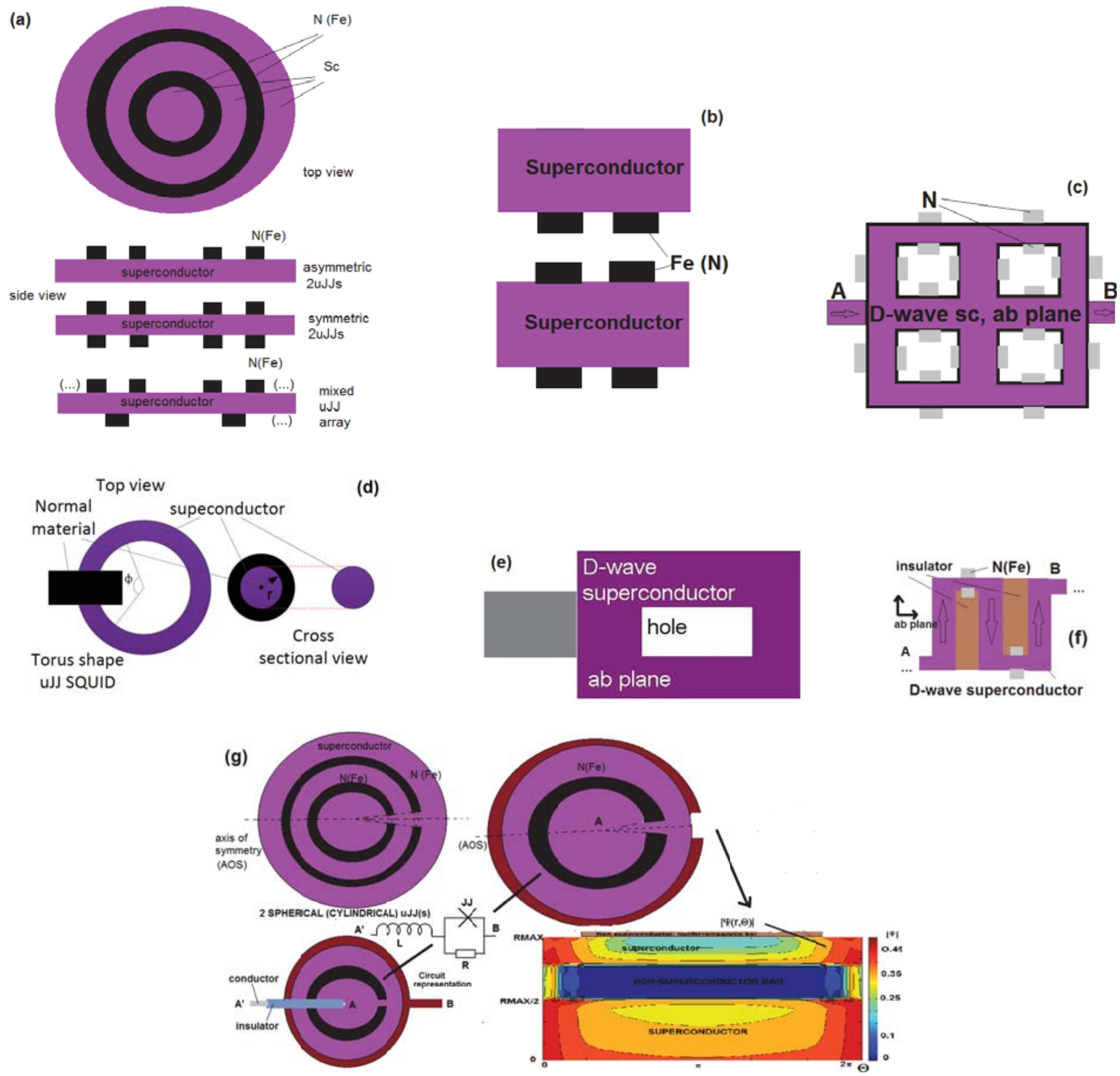

Fig. 6. Family of uJJ and FIJJ devices: JJ cylindrical array (a), asymmetric and symmetric JJ array (b),JJs matrix array (c), torus RF-SQUID (d), rectangular RF-SQUID (e), fault current limiter (f), cylindrical or spherical JJs in series (g), where JJ means Josephson junction.

TABLE I

SUMMARY OF FIELD INDUCED AND UNCONVENTIONAL JOSEPHSON JUNCTION DEVICE PROPERTIES. WE HAVE 3 BASIC GEOMETRIES: RECTANGULAR (RECT), CYLINDRICAL, SPHERICAL AND ALSO TOROIDAL. TOS STANDS FOR TYPE OF SUPERCONDUCTOR.

Nr	Device	Geometry	ToS	Implementation	Applications and Properties
1	1 uJJ, without Fe (Fig.1)	Rect	S	V.Easy	Non-Tunable device,e.g. detector of EM radiation
2	1 FIJJ, with Fe (Fig.1)	Rect	S	Easy	Tunable electronic device,e.g. detector of EM radiation
3	1 FIJJ or uJJ (Fig.2)	Cylindrical	Any	M.Easy	Detector of EM radiation
4	1 FIJJ or uJJ (Fig.2)	Spherical	S	Difficult	Isotropic or quasi-isotropic antenna
5	1 FIJJ or uJJ (Fig.6g)	Spherical	D	V.Difficult	Isotropic or quasi-isotropic antenna
6	FIJJ (uJJ) Asymmetric Array (Fig.3-4)	Rect	S	Easy	Detector of EM radiation, can be current limiter
7	FIJJ (uJJ) Asymmetric Array (Fig.6g)	Cylindrical	S	M.Easy	EM Antenna, can be current limiter
8	FIJJ (uJJ) Asymmetric Array	Spherical	S	Difficult	Isotropic or quasi-isotropic antenna
9	FIJJ (uJJ) Symmetric Array (Fig.6b)	Rect	S	Easy	Better tuning than in case of 1
10	FIJJ (uJJ) Symmetric Array (Fig.6a)	Cylindrical	S	M.Easy	Better tuning than in case of 2
11	FIJJ Symmetric Array (Fig.6g)	Spherical	S	V.difficult	Better tuning than in case of 3
12	FIJJ SQUID (Fig.6e)	Rect(ab plane)	D	Easy	Very sensitive to magnetic field
13	FIJJ SQUID (Fig.6c,e)	Rect	S	Easy	Very sensitive to magnetic field
14	FIJJ SQUID (Fig.6d)	Torus	S	V.difficult	Very sensitive to magnetic field
15	uJJ SQUID (Fig.6d)	Torus	S	V.difficult	Simple Weak link SQUID
16	FIJJ (uJJ) current limiter (Fig. 6.f)	Rect	S	Easy	Very useful
17	FIJJ (uJJ) current limiter (Fig. 6.f)	Rect	D	Easy	Very useful at 77K