Investigation of the border region of superconducting stripline.

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The morphology and structure of conductivity of edge of the YBCO strip is investigated. The AFM-modification of surface of the film, including its field evaporation is carried out. The area of edge having high resistance is allocated.

Now HTSC films are a basis for creation of high-Q devices for a microwave and Rf electronics. The most widespread kind of such devices are HTSC microstrip resonators, filters and delay lines [1]. The quality of these devices is determined by Q-factor and dynamic range. The dynamic range is limited from below by noise, and from above by microwave HTSC nonlinearity. The distribution of current in the superconducting strip is much non-uniform and has a maximum on the edge [2]. Thereof, the basic contribution to nonlinearity brings in the edge area. That is, its properties basically determine the dynamic range, and possibly the Q-factor of microstrip devices. The properties of edge area itself can strongly differ from properties of the HTSC film. Such difference is caused by the fact, that the strip structures are formed from HTSC films by the photolitography with subsequent liquid or ion beam etching. The area of edge cooperating with etching solution, changes the chemical structure and electrical properties.

In the given work the attempt is made to investigate the form and electrical properties of this changed area. For creation of strip structures in our work were used YBCO films by thickness up to 200 nm, made by laser ablation method [3] on substrates of LaAlO and NdGaO. Transport and microwave properties of films are described elsewhere [4]. The resonant structures made on the basis of these films by a method of photolitography and liquid etching had quality factor up to

$Q = 10^5$ [4]. The investigation of conductivity of the film near to strip edges was carried out by the atomic-force microscope (AFM) Solver-PM (NT MDT, Zelenograd) with conducting probe.

In a fig. 1a the AFM image of area of border of strip, and in a fig. 1b the scan of the current are shown. The characteristic picture of single pass of a probe is shown in a fig. 1c. From a fig. 1c it is visible, that as a result of etching at edge of the film the inclined plane under a corner about 40^{o} to the substrate was formed. It can be seen, that the conductivity begins strictly in a point of transition of an inclined plane in a horizontal surface of the film. From fig. 1b it is visible, that whole inclined plane at edge of the film is non-conducting, like the substrate. The picture of conductivity does not depend on a direction of pass of the probe. The breaks in conductivity on the horizontal surface of the film can have a various nature: heterogeneity of a film or dirt on its surface. The modification of the film was carried out with the help of AFM with a conducting probe. For this purpose the voltage up to + 5 V was applied to the conducting cantelever, the film was grounded. The probe nestled on the film and once was carried out across the bridge with constant pushing force. The results of modification are shown in a figs. 2 and 3. After modification the bridges have completely lost the superconducting properties at temperatures down to liquid helium temperature. In fig. 2a is shown the AFM image of the bridge after modification. On all trajectory of movement of the probe the ledge of height 10 nm was formed. Width of the ledge is about equal to the thickness of an edge of the probe. In a fig. 2b the profile is shown at single pass of the probe on the line shown in the fig. 2a. It can be seen from fig. 2b, that the ledge does not reach the edges of the horizontal surface of the superconducting bridge. In a fig. 3a is shown the AFM image of other bridge modified by a voltage 5 V. During modification there was an evaporation of the film on all its thickness. Width of the evaporated area is about 1 μm. That is essential more than the size of the end of the probe - 30 nm. From fig. 3a it is visible that the area of edge is, unlike HTSC film, neither evaporated, nor modified. It allows to assume, that the remained area is non-conducting. In a fig. 3b is shown the profile of the area of edge received at single pass of the probe on the line shown in the fig. 3a. It is possible to explain various results of modification of films by that the conditions of modification were reproduced not completely. The modification was made at identical temperature, voltage and force of pressing, but at various humidity, because the humidity was not controlled. From fig. 3 it is visible, that at field evaporation of the conducting film the nonconducting sites was not evaporated. Such sites are the edge area and structural defects which have arisen during the film deposition process. The width of the field evaporation area is 0,5 to1 μm. That is essential more than the sizes of the probe end - 30 nm. That allows to assume, that the remaining relief rather precisely reproduces a picture of conductivity, more precisely, its absence. It is visible, that on border there is a non-conducting area of width 0,5 to 1 microns and thickness equal the thickness of the film. It approximately corresponds to the sizes of granulas [5], on which borders the liquid etching is going. In result the layer of the one granula width with a non-conducting surface is formed. Probably inside this layer is kept small areas having conductivity, but they obviously have no contact among themselves, no less than contact to the film. Distance between these granulas at etching is increased in comparison with primary. Intergranular space is filled with products of reaction of the etching solution with the material of the film. To find out these conducting inclusions at measurements on a constant current it is impossible, but they can affect the microwave properties of resonant structures.

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