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IMAGING OF THE GRAIN STRUCTURE OF THIN HTS FILM BY A SINGLE-LAYER FLAT-COIL-OSCILLATOR TEST-METHOD (SFCO-TECHNIQUE)

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An imaging technique has been created (using a focused *He-Ne* laser beam as a probing signal) capable of imaging the grain structure of HTS thin films with 2–3 μ spatial resolution. It is based on detection of an inductance change of a single-layer flat pick-up coil, placed at the face of the specimen. This leads to frequency changes of a stable tunnel diode oscillator. Test device enabled 2D-mapping of the grain structure of the bridge-shaped YBaCuO film. Basically, the method is capable of imaging fine peculiarities of normal-metallic to superconductive phase transition and 2D-current distribution, as well as may identify localized defects in thin HTS-materials with sub-μ spatial resolution, using non-bolometric response. However, the achieved 2–3 μ resolution of a bolometric nature (in a given device with ~3 *mm*-size coil) is limited and depends on how narrow is possible to focus the probing beam, while the own spatial resolution of the tested flat-coil technique is better than 0,1 μ, and can be improved by 1–2 orders of the value by reducing pick-up coil size.

***Keywords*:** single-layer flat-coil-oscillator, SFCO, low temperature, laser scanning microscope, LTS, HTS, imaging.

Introduction. One of reasons why the nature of high-T_c superconductivity (HTS) is not clear yet is lack of methods for sensitive study of normal to superconductive (N/S) transition in HTS at start of the superconductive (SC) state formation [1]. The Meissner expel precursor and posterior fine effects detected in YBaCuO films recently [2, 3] point out the presence of unknown inter-phase physics near T_c [3, 4], to be studied experimentally in so tangled fluctuation temperature region. A single-layer flat-coil-oscillator method (SFCO-technique, Fig. 1) [5, 6], which could detect such fine effects (due to 6 orders relative resolution), seems may also help in studying properties of industrial HTS-materials. That is urgent, because as is admitted now the performance of industrial materials (first of all, their current-carrying ability) is close to the saturation. Achieved parameters are far from the ones in short samples [1]. This is also due to

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low abilities of acting methods, hindering to clarify reasons and mechanisms, leading to current limitation in HTS. Although widely used magneto-optical (MO) imaging method makes visible magnetic field entering into the HTS [7], nevertheless signals are noticeable at temperatures far below T_c only. There is need to improve a spatial-resolution of experiments too. Besides, MO-imaging may not visualize a distribution of currents inside the material. That enables a laser scanning microscopy (LSM) with about a micrometer spatial resolution (based on resistive tests [8]). However, it gives no signals below the temperature T_c, when the specimen loses its resistance. So, lack of high-resolution modern methods is still one of main reasons, why the nature of HTS is not revealed yet, and why the scientists failed in their attempts to improve current-carrying abilities of industrial HT*S*. While the problem how a cable production technology affects SC filaments/films original properties that the cables and tapes consist of (especially on their current-carrying capability) still remains one of topics of a prime importance in a large-scale high-T_c superconductivity area.

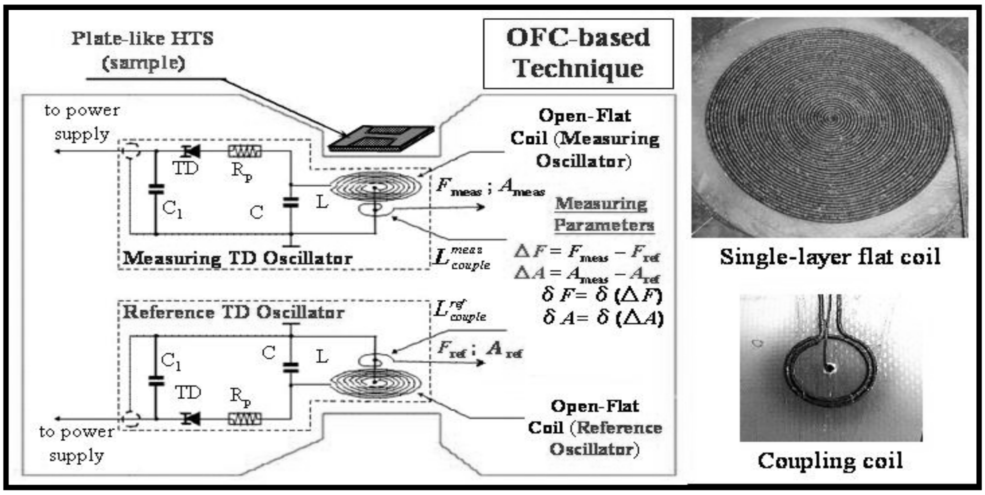

Fig. 1. Schematics of a single-layer flat-coil-oscillator based test-method, serving a basis for our imaging technique. Insets: the circular-shaped pick-up coil ($\varnothing_{coil}$ ~3 *mm*) and the coupling coil.

To conduct tests in HTS cables and tapes (all the more, in films and filaments they consist of), especially at start of transition one needs to use a method with super-high spatial resolution, enabling to extract peculiarities of properties in thin film structures (with small signals). If such a technique may also visualize current line distribution inside the HTS tapes, difficulties in area can be solved. We discuss an imaging technique based on the SFCO-method (Fig. 1).

Imaging technique: results and discussion. One of advantages of the SFCO-method is its ability to detect fine details of transition between normal and SC phases in tiny, plate-like objects. But while testing thin film structures, we deal even with smaller objects with too small signals. So, an instrument should have enough resolution for such objects too. The task is feasible, because one of the ways to improve spatial resolution of the flat-coil method is to reduce the coil size (up to the sample size). We see no problems for test devices with coils up to 1 *mm* in diameter. Such perfection of the method will permit to reach 5–6 orders signal to noise ratio even for $0{,}5\times 0{,}5\ mm^2$ area samples [6]. But for improved technique one needs lithographically made coils [9], instead of the hand-made present ones shown in Fig. 1. Such a serious perfection of the method resolution is crucial for μ-size HTS-structures to essentially increase the measured signal level.

Due to such high capabilities of the SFCO-method, an imaging technique was created using a focused laser beam as a probing signal capable of imaging properties of HTS thin film structures. It operates as follows: irradiating locally film by the laser beam, the highly sensitive SFCO-technique, schematically shown in Fig. 1, allows detection of a local density of the Cooper pairs by scanning the laser spot over surface of a film (Fig. 2). If the local pair density is modulated by the transport current (or by other physical/technological factor), the technique in Fig. 2 may visualize 2D-map of electron pairs density, and so, the current distribution. Basically, the own resolution of the given flat-coil device (with ~3 *mm*-size coil used) is ~0,1 μ. But the resolution of the present imaging technique is limited not by the abilities of the flat coil method. It depends on how narrow is possible to focus the laser beam by lenses. The minimal value of the laser spot is ~1,5 μ, if use precisely focused *He-Ne* laser beam as a probing light.

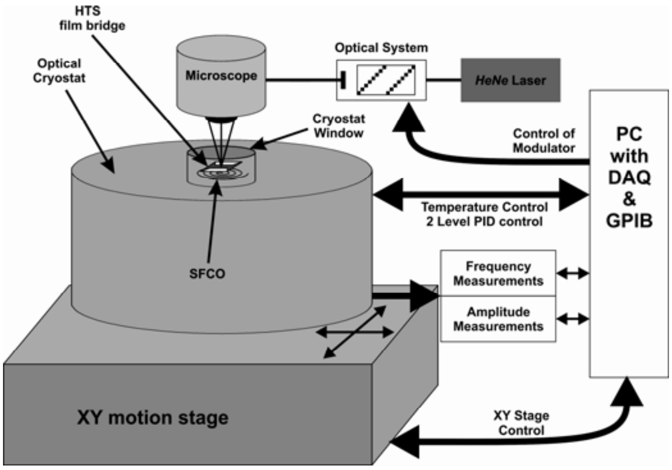

Fig. 2. Schematics of the SFCO-method based imaging technique, which uses a focused *He-Ne* laser beam as a probing signal.

Thus, created imaging device enabled 2D-mapping of the grain structure of tested YBaCuO film-bridge (Fig. 3). It also permitted to visualize changes in a surface impedance of the same bridge at N/S-transition (Fig. 4). Achieved in our experiments resolution is 2–3 μ. That is close to the focused spot (~2 μ) of the used *He-Ne* laser beam.

Note that the flat coil's testing radio-frequency field may also be distorted by the low-T_c SC (LTS) normal-metallic film, during its N/S-transition. But difference in distortion is much more in the case of HTS. That is due to higher value of a skin depth in oxide SC in comparison with the ones in LTS. This is because of considerably higher resistance of HTS in a normal state. So, the *MHz*-range testing radio-frequency field, applied at a face of the HTS-film, penetrates across the whole thickness of the thin film in a normal state and screens in SC state almost completely. In contrast to this, LTS-film with the same thickness screens strongly applied field in both normal and SC states. So, the method may be applied to study N/S-transitions of LTS-films too, if the thickness of the film is less than the depth of its skin layer.

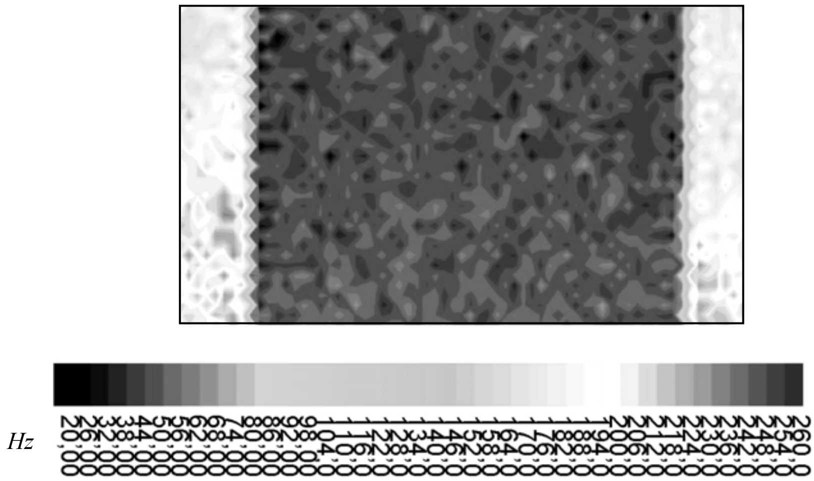

Fig. 3. 2D-map of a surface of 4,0 *mm* long and 0,2 μ thick YBaCuO bridge, detected by frequency of oscillator. Dark (central) area (small numbers) represents the grained structure of a bridge (200 μ wide (horizontal) and 100 μ long (vertical)). Bright region (left and right sides) is the substrate. Mapping duration is ~3,5 hours. T=77 K. Scan step w~1,5μ, laser power P~0,1 mW, pulse duration – "switched on" ~0,7 s (provides enough signal level), "switched off" ~3 s (thermal flux could disperse in a laser spot).

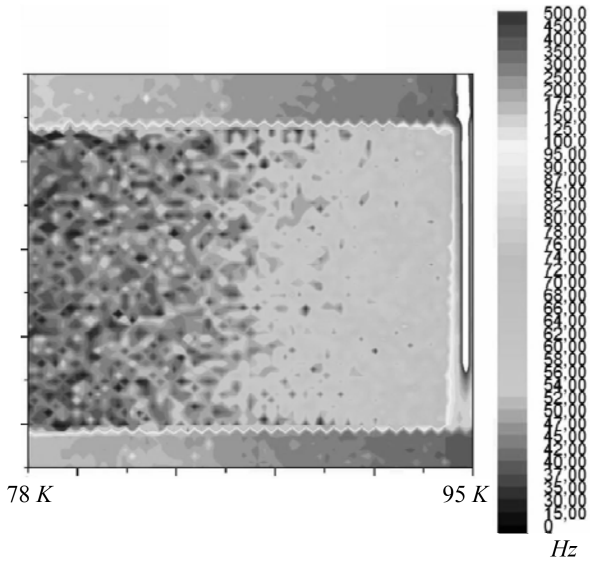

Fig. 4. 2D-imaging (visualization) of a phase transition of the tested YBaCuO composition HTS thin film bridge (200 μ wide) from the superconductive (T~78 K) to normal (T~95 K) state.

Note also that according to our earlier study [10] the flat-coil method is basically capable of imaging 2D-current distribution in thin film structures with sub-micron spatial resolution, using bolometric or non-bolometric response. Its modification (if combined with MO-imaging or with scanning electron microscope (SEM) systems) will also give the similar results in the field of superconductive tapes and coated conductors. As a result, such a method may permit to clarify the reasons and mechanisms leading to the current limitations in industrial HTS-materials.

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Բարակ ԲՋԳՀ թաղանթի հատիկային կառուցվածքի տեսանելիացումը միաշերտ հարթ կոճով գեներատորի մեթոդով (SFCO-տեխնիկա)

Ստեղծվել է 2–3 մկմ տարածական լուծունակությամբ բարձրջերմաստիճանա-յին գերհաղորդիչ (ԲՋԳՀ) բարակ թաղանթների հատիկային կառուցվածքը տեսանելի դարձնող տեխնիկա, որում օգտագործվում է He-Ne լազերի ճառագայթը որպես զոնդավորող ազդանշան: Այդ տեխնիկան հիմնված է միաշերտ հարթ կոճի ինդուկտի-վության փոփոխության վրա, երբ կոճը հպվում է տափակ նմուշի երեսին: Դա հանգեցնում է թունելային դիոդով ակտիվացվող կայուն գեներատորի սեփական հաճախության փոփոխմանը: Ստեղծված սարքը թույլ է տալիս ստանալ YbaCuO թաղանթի (կամրջակ) հատիկային կառուցվածքի երկչափ պատկերը: Ընդհայնրապես այս մեթոդը կարող է տեսանելի դարձնել նորմալ–գերհաղորդիչ ֆազային անցման նուրբ առանձնահատկություններն ու հոսանքների երկչափ բաշխումը, ինչպես նաև բարակ ԲՋԳՀ նյութերում բացահայտել տեղային արատները ենթամիկրոնային տարածական լուծունակությամբ: Բայց ջերմային բնույթի ազդանշանների միջոցով գործող ու 3 մմ չափեր ունեցող կոճով սարքում ձեռք բերված 2–3 մկմ լուծունակությունը սահմանափակվում է ու կախված է նրանից թե որքան է հնարավոր կիզակետել զոնդավորող ճառագայթը: Մինչդեռ փորձարկված հարթ կոճով գենե-րատորի սեփական տարածական լուծունակությունը 0,1 մկմ-ից ավելի է ու հնարավոր է 1–2 կարգով էլ մեծացնել՝ փոքրացնելով դետեկտող կոճի չափերը:

Визуализация гранулярной структуры ВТСП-пленки с помощью генератора на плоской однослойной катушке (SFCO-техника)

Создана техника, способная визуализировать гранулярную структуру тонких высокотемпературных сверхпроводниковых (ВТСП) пленок с пространственным разрешением 2–3 *мкм*, использующая фокусированное излучение *He-Ne*-лазера в качестве зондирующего сигнала. Техника основана на детектировании изменения индуктивности плоской однослойной приемной катушки (ПОК), расположенной на поверхности образца. Это приводит к изменению частоты автоколебаний стабильного генератора на туннельном диоде. Созданный нами прибор позволил получить двумерную картину гранулярной структуры мостика из YBaCuO-пленки. В принципе, этот метод способен визуализировать тонкие особенности сверхпроводящего фазового перехода и двумерного распределения сверхтекучих токов, а также идентифицировать локализованные дефекты в тонких ВТСП-материалах с субмикронным пространственным разрешением с помощью неболометрического отклика. Хотя и на данном приборе с 3-х миллиметровой приемной катушкой нами достигнуто разрешение 2–3 *мкм*, обусловленное болометрической природой, но предельное разрешение этого конкретного визуализирующего прибора ограничено и зависит от того, насколько удастся сфокусировать пробный лазерный луч. В то же время собственное пространственное разрешение SFCO-техники с 3-х миллиметровой катушкой лучше, чем 0,1 *мкм* и даже может быть улучшено на 1–2 порядка путем уменьшения размеров приемной катушки.