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METHOD FOR MEASURING THICKNESS OF THIN OBJECTS WITH A NANOMETER RESOLUTION, BASED ON THE SINGLE-LAYER FLAT-COIL-OSCILLATOR METHOD

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A method for measuring of any composition films and tapes thickness with a nanometer resolution is suggested and validated experimentally. That operates on the base of a single-layer flat-coil-oscillator technique. A laboratory prototype of a device is designed and created, based on this method. Besides, PC operation in a "NI LabVIEW" software environment, as well as preliminary tests and calibration of the created device is implemented. It may find variety of applications in a research and in high-tech technology.

***Keywords*:** Single-layer Flat-Coil-Oscillator method, a nanometer resolution thickness measuring and controlling technique, high-T_c superconductive films and tapes.

Introduction. In a micro- and, especially, in a nanotechnology there is a great need of measurement methods (and devices on that base) that may enable measuring of the thicknesses of thin-film nanostructures, created during a technological processes with a few nanometer precision [1].

Presently, optical devices are used for that purposes. They operate on the basis of interference, therefore, their resolution is close to the order of the measuring light's wavelength $\lambda_{opt}/2$ ~250 *nm*. There are also more complicated *"ellipsometric"* optical devices [2], based on the polarization of light, which allow to enhance the resolution of measurements by one more order of magnitude (almost 10 times), approaching it to the few tens of nanometer. However, unfortunately, they also do not permit to reach the nanometer level of resolution, and besides, they are enough expensive and also complex devices.

As opposed to the corpuscular and wave microscopes (which, in principle, can't solve the problem of measuring/detection of a nanometer thicknesses and depths in a perpendicular of the sample face direction [3]), such resolution (even, much better) show probe microscopes (tunneling [4–5] and atomic force [6]), however, they are too much expensive, and besides, incomparably complicated

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devices. Therefore, it is not reasonable to use them at standard (everyday) technological processes. In addition, technical staff should pass special courses before getting permission to exploit such a complex technique. That's why for a long time one needs to get simple and cheap ways to solve this problem.

Taking into account all these, in this work we could elaborate and create a fully new method for measuring of the thickness of thin films and tapes. It enables to measure the thickness of any composition film – with about 1–2 *nm* resolution in about 1 *mm* range. Alongside with its high resolution and wide dynamic range, as well as alongside with its simplicity and cheapness, the method has also other advantage: it doesn't require additional processing of the specimen under study. That is especially comfortable in case of biological objects.

Description of the Method. On the basis of operation of our new method for detection of thicknesses of the films and tapes underlies a single-layer flat pick-up coil based oscillator, activated by a low power (backward) tunnel diode (TD) – a single-layer flat-coil-oscillator (SFCO) technique [7–8]. Its principle of operation is shown in Fig.1. Radiofrequency (RF, *MHz*-range) testing magnetic field distribution near the coil is illustrated in Fig. 1, a. When normal-metallic plate approaches to the coil (Fig. 1, b), it shields the said field distribution – due to neglectablly-small depth of the "*skin*"-layer in such a plate at the *MHz*-range – resulting in a strong distortion of the coil testing field distribution. This leads to the corresponding changes in a measuring TD-oscillator frequency – just this is the measuring parameter in the SFCO-technique.

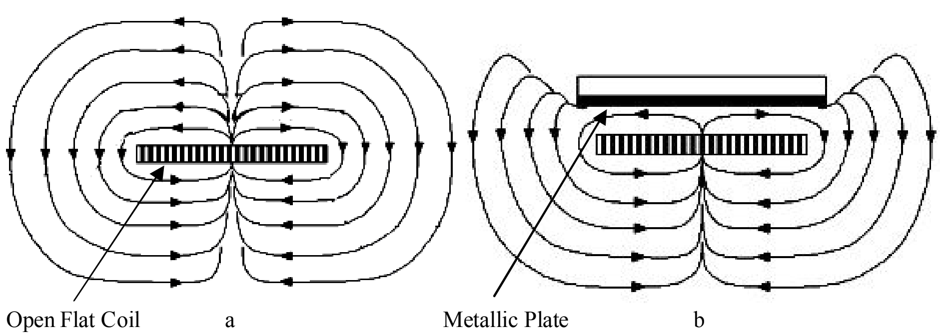

Fig. 1. Principle of operation of the single-layer flat pick-up (detecting) coil based oscillator (SFCO) technique [7–8].

So, our new method for measuring the thicknesses of the films and tapes is based on the SFCO unique technique. Schematics of such a way created laboratory device is shown in Fig. 2. It operates as follows.

Optically polished sample stage and cantilever enable springy compression of the measuring spherical or needle-type probe to the specimen. That is done due to elastic properties of the used cantilever (see Fig. 2). A normal-metallic plate (made of, for example, printed copper circuit board) is attached to its free end on the back of probe. Displacements of this plate lead to the positioned near flat-coil's testing RF-field's distortion (shielding). That results in the frequency shift of the flat-coil based TD-oscillator. During the measurements the sample is placed on the sample stage, under the probe (see Fig. 2), and moves. During such a scan, probe goes up and down by the thickness and roughness of the sample surface. That leads to changes of mutual distance between the detecting flat coil and shielding metallic plate attached to the cantilever, which results in corresponding changes of the measuring TD-oscillator harmonic oscillations frequency. Therefore, tracking frequency shifts, one may detect the thickness of the sample and extract the scope of its surface roughness. So, in a suggested by us method changes of the sample thickness and/or its surface roughness during the linear scan of the sample lead to the testing TD-oscillator frequency shifts – this is just the measuring signal.

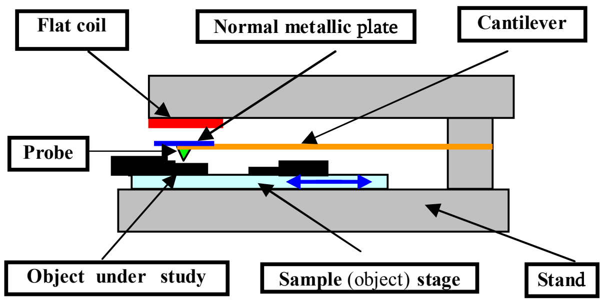

Fig. 2. Schematics of the created prototype device, based on our new idea for measuring the thicknesses of the films and tapes.

Actually, in a tested device two TD-oscillators are used with almost identical characteristics (with close frequencies). Due to this, influence of external and internal factors (such as temperature's and tunnel diode bias-source voltage's instabilities, drifts and other factors) on frequencies of the said oscillators, both are similar. That is why difference between the frequencies of oscillators, designed in such a "compensation" (balanced) scheme, depends on mentioned factors negligibly slow [7–8]. Therefore, use of such a balanced couple of "similar" oscillators enables to avoid experimentally consideration of the influence of mentioned (as well as some other, non-mentioned) external and internal factors, which are usually out of control during the tests [7]. In a tested $\varnothing_{\text{coil}} \sim 7$ *mm* flat coils based prototype TD-oscillators were activated at the frequencies close to the 25 *MHz*, while the difference between their frequencies was about 500 *kHz*. Their stability was better than ± 10 *Hz* at the room temperatures.

Calibration of the Prototype. Before the tests of the created device it was calibrated. For that the shielding metallic plate was approached (and moved away) to the measuring coil face by means of the «*X-Y*» stage, driven by stepping motors (with 1 μm step, on 0.2–0.7 *mm* distance from the coil), and the oscillator frequency shift was detected. Results of such an experiment we bring in Fig. 3.

The horizontal axis in Fig. 3 shows changes of mutual distance between the flat coil and shielding plate during calibration experiments (at the real experiments that corresponds to changes of the thickness of object under test), while the vertical axis corresponds to the related changes of the measuring TD-oscillator frequency (changes of difference frequency). The solid line is the measuring data (test data with a too small step of about 1 μm are densely merged into the shown solid line), while dashed line is the linear approximation of experimental data. As is seen from the Fig. 3, in enough wide region (more than 0.5 *mm*) readout of the tested prototype is linear vs. position of the shielding plate (vs. the thickness of the object under test). Starting from the slope of the curve under discussion one may estimate that 1 *nm step of the metallic plate brings to the* 6 *Hz shift of the measuring oscillator frequency*. Taking into account the said stability of the created technique

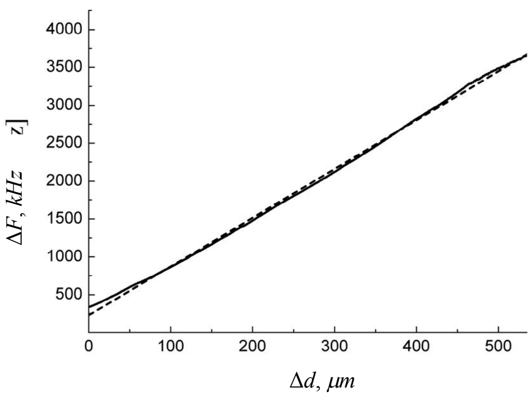

Fig. 3. Calibration curve of the thickness measuring prototype.

at room temperatures of about ±10 *Hz*, we may state that the resolution of our thickness measuring prototype is around 1–2 *nm*.

Starting from the obtained calibration data, we organized also PC control of the created prototype device in the "NI LabVIEW" software environment. In other words, developed software enables to register frequency signal-outputs from the prototype and converts them to the values corresponding to the thickness of the object under test, using calibration data. Created device also permits to study the thickness variations of thin objects, placed on the «*X*-*Y*» sample stage, and estimate the roughness of samples' surface along (schematics see in Fig. 2). That is possible to do in our prototype device with 1 *μm* step, by means of the sample movement «*X*-*Y*» stage, driven by the stepping motors along both of axis, and by use of the corresponding PC software control.

Test Data of the Prototype. Preliminary test of the created device was done by use of mylar tapes with various (but known) thicknesses. That enabled to make one more (independent) calibration of this technique, which agrees well with the results above (see Fig. 3). Such tests were done as follows:

1) before the start of measurements, iron probe was pressed to the optically polished sapphire sample stage (see Fig. 2). In that "zero" position of the probe the frequency of the testing flat-coil oscillator was measured. Its value depends on the mutual distance between the coil and normal-metallic (copper) plate, fixed on the back of the probe (attached to the free end of the cantilever (see Fig. 2).

2) then the same value was measured, but in this case mylar tape was placed between the spherical probe and the sapphire sample stage. Five different measurements were done during this set of tests, using different depth tapes: $d = 12$, 24, 36, 48 and 60 *μm*.

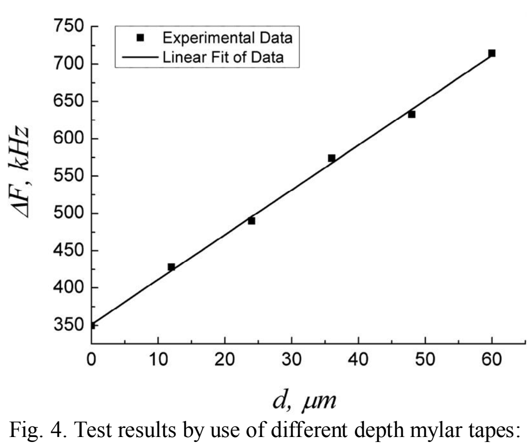

Fig. 4. Test results by use of different depth mylar tapes: $d = 12$, 24, 36, 48 and 60 *μm*.

As a result of our tests the dependence of the measuring TD-oscillator frequency vs. the thickness *d* of the tested tape was plotted in Fig. 4. Taking into account the accuracy of our measurements (±10 *Hz*), one may estimate the resolution of the created by us thickness measuring prototype, using the slope of the curve, presented in this figure. And again, we came to the same resolution (1–2 *nm*) – from Fig. 4 we can receive: 360000 $Hz/60\ \mu m = 6\ Hz/1\ nm = 12\ Hz/2\ nm \cong$ $\cong \pm 10\ Hz/2\ nm$. That is because of the reliabile mesurements conducted in this work.

Conclusion. Taking into account so high resolution (1–2 *nm*, in a dynamic region of about 1 *mm*) achieved in the flat-coil method based our thickness measurement prototype during its preliminary tests, we suppose that a thickness (depth) measurement this new method (and devices, created on that base) may find variety of applications in the research work, as well as in technology. In particular, one may use such a technique in micro- and nanoelectronics, as well as in high-temperature superconductive (HTS) film production technology. It can be used also in production process of HTS-tapes (containing inside the said HTS-films). Such a precision research instrument might be used also in various types of technological equipments, making characterization of the said tapes.

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Թաղանթների հաստությունը նանոմետրական լուծունակությամբ չափող մեթոդ՝ հիմնըված միաշերտ հարթ կոճով ինքնագեներատորի վրա

Առաջարկվել ու փորձնականորեն հիմնավորվել է կամայական բաղադրությամբ թաղանթների և ժապավենների հաստությունը նանո-մետրական լուծունակությամբ չափող ու գրանցող, միաշերտ հարթ կոճով ինքնագեներատորի վրա հիմնված մեթոդ: Իրականացվել է այդ մեթոդով գործող սարքի լաբորատոր մանրակերտի մշակում, ստեղծում, “NI LabVIEW” ծրագրային միջավայրում դրա աշխատանքի համակարգչային ղեկավարում, ինչպես նաև ստեղծված համակարգի նախնական փորձարկում ու սանդղակավորում: Այն կարող է լայն կիրառություն գտնել ինչպես հետազոտական խնդիրներ լուծելիս, այնպես էլ միկրո- և նանոտեխնոլոգիայում:

С. Г. Геворгян, С. Т. Мурадян, М. Г. Азарян, Г. А. Карапетян.
Метод измерения толщины пленок с нанометрическим разрешением, основанный на автогенераторе с плоской однослойной катушкой

Предложен и экспериментально обоснован метод измерения толщины пленок и лент с нанометрическим разрешением. Он основан на автогенераторе с плоской однослойной приемной катушкой. Осуществлены разработка, создание, калибровка и предварительное испытание лабораторного макета созданного по этому методу устройства, а также организовано компьютерное управление им в программной среде «NI LabVIEW». Метод может найти широкое применение как при решении научных задач, так и в микро- и нанотехнологии.