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Application Notes

SPM methodology

INVESTIGATION OF SURFACE BY MEANS OF SNOM

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Investigation of surface by means of SNOM (Near-field scanning optical microscopes)

As well known the classical resolution limit of conventional optical microscopes which arise from diffraction on entrancetive objective is equal to $\lambda/2$. It is deduced from approximation of flat waves, i.e. objective situating at the wave region of object radiation and light waves which come from this object may be considered as flat waves. Then limit is deduced from distribution light field in image plane of objective with help of Fraunhofer diffraction on round aperture. Distribution of signal in image plane looking so:

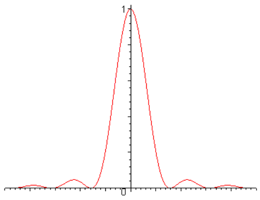


Fig.1.

Figure shows that main portion of energy (about 84%) is contained in central diffraction disk. This Airy disk will be image of luminous point.

In accordance to Rayleigh criteria a resolvable distance of device lmin is equal to distance between two luminous points on conditions that distance between centers of Airy disks equals radius of one disk. From above we may conclude that $l_{min}=0.61\frac{\lambda}{n\cdot\sin\alpha}$, where n-refraction index of object space, $2\cdot\alpha$ — aperture angle (entrance aperture). Generally $n\cdot\sin\alpha$ less than $1.5 \Rightarrow l_{min} \approx 0.4\cdot\lambda$. Then we may say that objects less than $0.4\cdot\lambda$ does not resolve by means of conventional optical microscopes. It is principle restriction.

In order to examine the resolution limit of SNOM we will use so-called model of two-points doublets, where probe and sample are considered as balls with small diameters (in compare with wave length and distance between probe and sample). From this model we may find that extremely resolution because of absorption is

$l_{min}=2\cdot R_0\cdot\left(\frac{|ImA|}{3\cdot ReA}\right)$, by $2R_0=\sqrt[3]{2}\cdot(\alpha_1\cdot\alpha_2)^{\frac{1}{6}}$ and $A=\alpha_1\cdot\alpha_2$.

Where $\alpha_1(\omega)$ - polarizability of first doublet (probe);

$\alpha_2(\omega)$ - polarizability of second doublet (sample);

Here assumed that $|\alpha_1|<<|\alpha_2|$ and Re ***ReA***$>>|ImA|$ (small absorption).

Then extremely resolution is about 10 nm.

In present time SNOM able to resolve structure with characteristic scale 50-100nm. Investigation of surface with the help of SNOM has series of advantage in comparison with conventional optical microscope, namely:

high topographic resolution of the sample (about few tens of nanometers);

a numerous methods for investigation of surfaces;

possibility to obtain distribution of optical properties of surface with high resolution;

Next image shows appearance of SNOM SNC080.

Fig. 2.

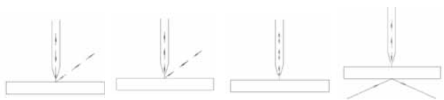
SNOM SNC080 can work in next optical modes:

a) illuminating of surface by means of optical fiber and collecting reflected light by optical system;

b) illuminating by far distance source of light and collecting light by fiber;

c) illuminating and collecting light by means of optical fiber;

d) illuminating surface by far distance source of light and collecting beam transmitted through sample.



a b c d

Next image shows optical scheme of microscopes, which explain these regimes:

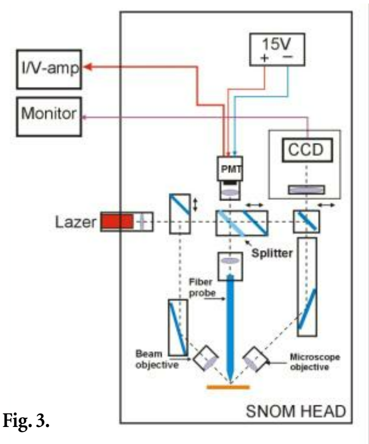


Fig. 3.

Intensity of optical signal obtained by detector in each points of measurement is used for forming of SNOM image. For example ,if sensor collect reflected light, then absorption factor and reflectivity factor may be studied. Let it be coefficient $r=I/I_0$, where I-intensity of useful signal, I_0 - intensity of incident light. The more r, the bigger reflectivity factor. If r is small then it is necessary to have great ratio of signal to noise. It follows that nonoptical schemes of holding of probe is very useful in such cases.

SNC080 may be used for investigation of cellular creations, molecule of DNA, viruses , property of semiconductors , for obtaining structures with characteristic scale about 1/10 wavelength , for realization of spectroscopy of biological object (as a rule with help of UV radiation) , for observation of process of chemical reaction , also as means of conventional microscopes.

To hold the optical probe near surface nonoptical schemes with quartz as sensor is used . It allows to increase ratio of useful signal to noise in comparison with optical holding schemes. It is very important at operations with limiting resolution. Also photoinduced carries does not appear. It is necessary requirement when some properties of semiconductor are investigated.

At the heart of nonoptical method for obtaining of information about surface lies idea to use response of quartz attached to optical fiber on interaction with surface. System fiber-quartz is excited in transverse vibrations with help of external feed element on quartz resonance frequency . Further piezoeffect is used: in the presence of mechanical oscillations electrical outputs of quartz have voltage response, which is used as information signal about amplitude of fiber oscillation. Next image shows Shear-Force schemes:

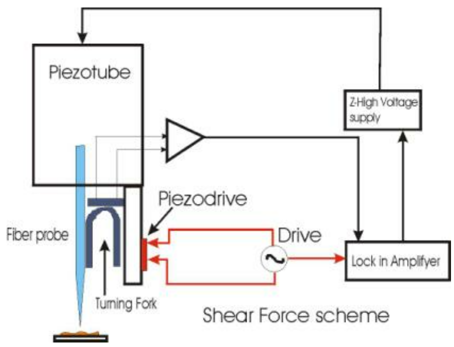


Fig. 4.

This work can be discribed so: at approach to the surface the tip of optical fiber begin to interact with surface. As a result a quality of quartz decreases and its resonance frequency shifts. Response from quartz diminishes because of these effects ant it is registered feedback system. Thus information signal about probe-surface distance is electrical response of quartz, which is proportional to its mechanical oscillation. Also this response has information both vibration amplitude and phase and oscillation frequency. For example, it is necessary in the case of measurements of local rigidity.

This Shear-Force mode can work in different modes:

noncontact mode provides measurements of Van der Waals forces, electronic, magnetic forces near the surface, where force may be as small as 10-12 Newton. It allows to investigate very sensitive and weakly connected with surface objects without rupture and displacement.

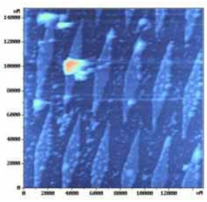
fiber do not interact with surface most of period time and interact with sample weakly. It is character feature of semicontact regime. When fiber come to area of repulsion interaction increase sharply. Fiber lose excess of energy during this interaction. According to type of interaction phase shift of fundamental harmonic with respect to actuating signal may be changed. Also amplitude and phase of higher harmonics may vary. Basic effect is limitation of amplitude of oscillation at distance which probe and surface have in free state, i.e. fiber can oscillate up to contact with surface only.

In some cases regime of registration of feedback error help to distinguish small features on topographic. This regime may be considered as intermediate between regime of constant force and constant height, when velocity of adjustment of feedback follows the slightly sloping variations of relief and does not follow the strongly sloping variations. Then at the time of intersection of small nonuniformity scanning will be at constant height of scanner. As a result of the slightly sloping variations will be weakly contrast and the strongly sloping variations - sharp contrast. It may be useful for finding of small nonuniformity on large field on background of big flat relief features. In that case contrast increase with increasing of velocity. Optimal parameters select for each case separately.

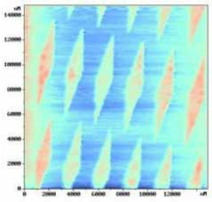
Contrast image is typical for phase signal because phase displacement between exciting oscillations and quartz response depends upon properties of surface. Due to this property the phase detection microscopy may be used for making of graphical mapping such properties as elasticity, adhesiveness and friction.

Force modulation regime may be used as means of study of elastic properties of sample because quartz response in that case depends upon these properties.

Choice of parameters in Shear-Force mode is very important. If coefficient of feedback increase (without generation) then died time increase hence quality of image improve. It shows next image:



F. 5.



F. 6.

Parameters of first scan is Fbgain=0.220, Spnt=3.96 nA, Velocity=136833 A/s.

Second - Fbgain=0.220, Spnt=3.96 nA, Velocity=136833 A/s.

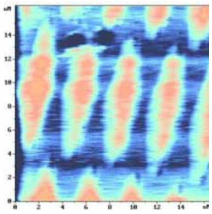
If big Spnt value is used then fiber interact with surface strongly hence amplitude of oscillations violently decrease and image quality become worse.

It may be seen in Figure 5.

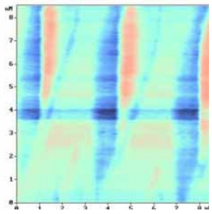
If feedback coefficient and gain factor are near oscillation threshold then parasitic component appears in the form of rip.

As already said above small Spnt is used in noncontact mode, big Spnt -in semicontact. To obtain the best scan of surface it is better to make measurements in semicontact mode.

Also scanning velocity depends upon the quality of image. If velocity is small -quality of image is better. Next images show this property:



F. 7.



F. 8.

Parameters of first scan is Fbgain=0.531, Spnt=0.871nA, Vel=254342 A/s; second - Fbgain=2.042, Spnt=1.137 nA, Vel=57442 A/s;

From figures we see that first picture have diffuse image, at the same time second image is sharp. It may be explained as:

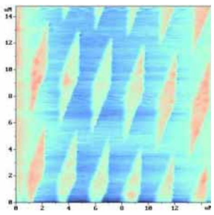
1. Feedback coefficient bigger , but generation is absent;

2. Spnt bigger , that give rise to higher sensitive , but fiber don't stop oscillations;

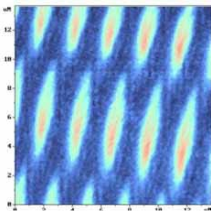
3. Velocity less;

Optimal parameters in Shear-Force mode select for each sample separately.

As already said above distribution of light field repeat relief of surface. This correlation easy to see from next scans, which were made on optical lozenge lattice simultaneously.



F. 9.

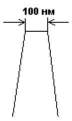


F. 10.

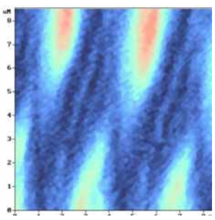
Here the first scan shows a topography of surface, second- optical characteristics.

Next scan of optical lozenge lattice demonstrate the limitation resolution of SNOM.

Linear dimension on the angle of rhomb is 100 nm, i.e.



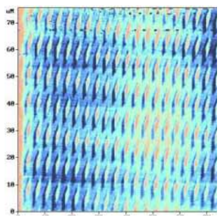
F. 11.



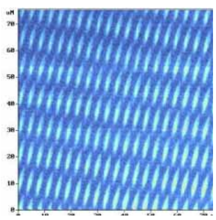
F. 12.

Next image demonstrate optical scan of this lattice at the limitation resolutionv

Next two figures display the same lattice (the other field of scan) in regime of topography (first) and optics (second).



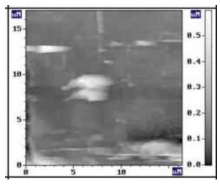
F. 13.



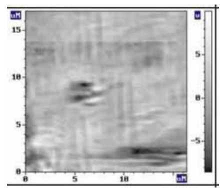
F. 14.

Parameters: velocity 246442 A/sec, step of scanner 1228.7 A/sec, vertical and horizontal resolution 256x256 points, Fbgain=0.639, BiasV=0.420 V, Spnt=0.761 nA.

Next two images show the topography (first) and optics (second) of leatropic liquid crystal. These scans have correlation, moreover SNOM image besides topography information have information about optical irregularity induced by irregularity of orientation of molecules respect to plane of polarization of laser emission.

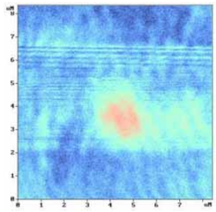


F. 15.



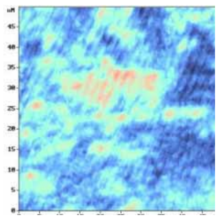
F. 16.

With help of SNOM may study properties of semiconductors. For example, optical scan of silicon:



F. 17.

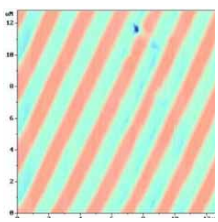
From image we may see that some optical irregularity take place due to absorption molecules. Next sample is rectangular lattice with period 3 µm. It's optical scan:



F. 18.

Parameters: Velocity 136883 A/sec, step 318.0 A, horizontal and vertical resolution 256x256 points, Fbgain=3.834, BiasV=0.420 V, SPnt=1.853 nA.

Next image demonstrate work in Shear-Force mode. Sample is rectangular lattice with period 3 µm.



F. 19.

Parameters of scan: Fbgain=2.182, Spnt=0.969 nA, Vel=94833 A/s.

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