Experimental investigation of the spectral characteristics of open resonance systems for radiospectroscopy

1. Experimental investigation of spectral, field, energy and polarization characteristics of open resonant systems

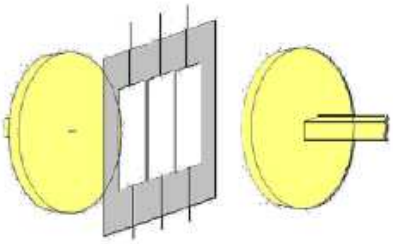
Responsible: V. N. Derkach (Ph.D. in Phys. and Math.), R. V. Golovashchenko (Ph.D. in Phys. and Math.), A. S. Plevako

Results of investigation

1.1. Open resonators

On the base of study of the properties of open two-mirror resonators (OR) it is designed and created:

- resonance cells for radiospectrometers and pumping systems of polarized nuclear targets;
- differential method of measurement of parameters of liquid dielectrics.



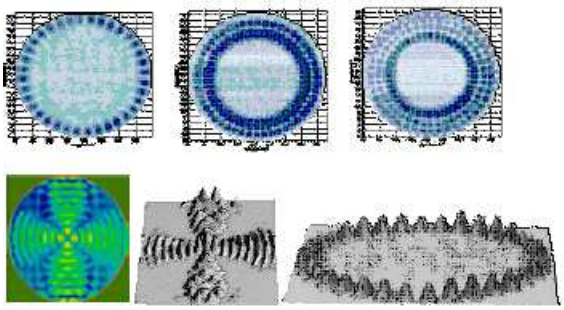
$$\varepsilon' \approx \varepsilon_k + \frac{3\sqrt{\pi}\Delta L}{h\xi e^{(-\xi^2)}(1+2\xi^2)}$$

$$tg\,\delta \approx tg\,\delta_k \left[1 + \frac{(\Delta L - \Delta l)3\sqrt{\pi}}{h\xi e^{(-\xi^2)}(1+2\xi^2)\varepsilon'_k - \Delta L}\right]$$

1.2. Open barrel-shaped resonators

On the base of the study of properties of open barrel-shaped resonators (OBR) it is designed and created:

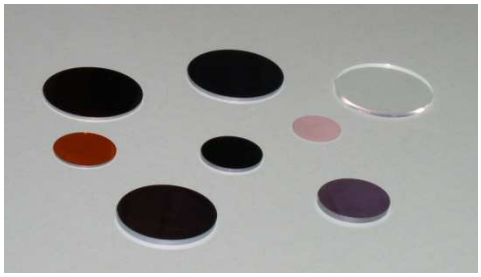
- multichannel resonance cells for diagnostics of plasma-beam systems;
- hygrometers of paper tape, gaseous and free-flowing media.



1.3. Open disk dielectric resonators with whispering gallery modes

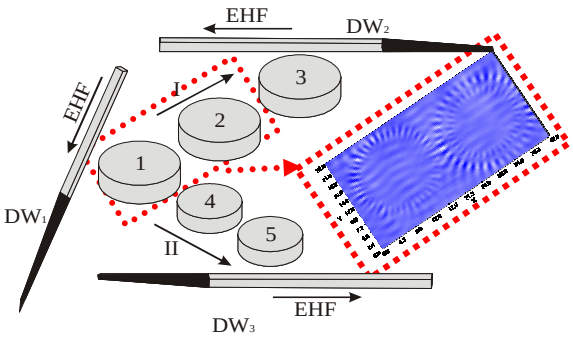
Main properties of multimode disk dielectric resonators (DDR) with whispering gallery modes (WGM) are experimentally investigated. The resonance cells for the low-temperature radiospectrometer and cells for dielectric measurements are design on their basis.

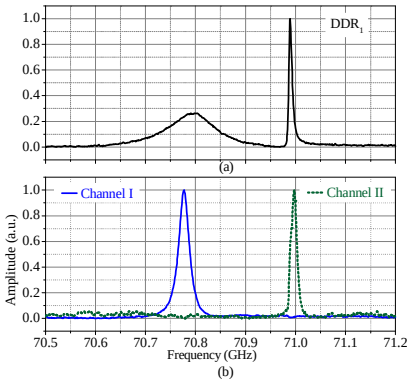
DDR with WGM are made with optical precision from radiotransparent materials (quartz, sapphire, CVD diamond and others) and their spectral, field and power characteristics are investigated. The results are used to solve practical problems.



1.4. Coupled disk dielectric resonators. Controlled structures on the base of coupled DDR

The possibility of design of controlled structures on the base of coupled disk dielectric resonators (DDR) in the millimeter waveband is shown. The work of two-channel selective splitter are demonstrated.

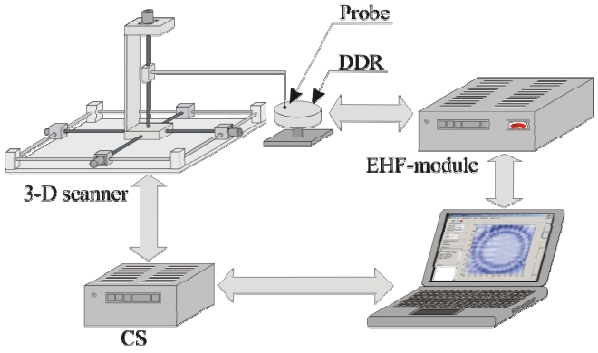


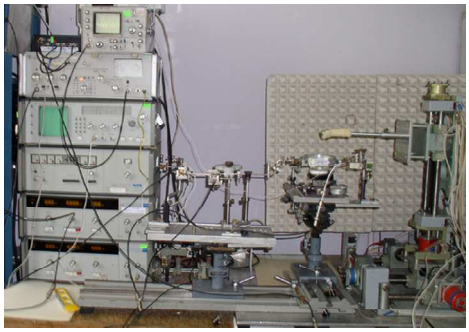


Experimental equipment

Computerized test benches for investigation of characteristics of OR and diffraction fields in the millimeter waveband.

- Computerized stand: 3-axis scanning device enables to move the passive (active) probe in the volume of 250x250x250 mm^3 with the minimum step of 0.1 mm and a maximum velocity of 5 mm/sec on an arbitrary trajectory, which is determined by software. It is used to measure spectral, field and energy characteristics of OR in the gigahertz frequency band.





- Computerized stand for measuring the spatial characteristics of scattering fields of the millimeter waveband by fractal and plane-chiral resonance structures in free space.

The resonance cell for the cryogenic radiospectrometer “TORNADO” and the radiospectrometer of quantum liquids; cuvettes for the measurement of parameters of liquid dielectrics are designed on the base of DDR.

The detailed presentation of the results is given in the publications:

1. V. N. Derkach, O. Ye. Marykivsky, “Development of microwave moisture meter for free-flowing materials,” Telecommunications and Radio Engineering, Vol. 51, No. 6–7, 1997, pp. 167–170.
DOI: http://dx.doi.org/10.1615/TelecomRadEng.v51.i6-7.270

2. V. N. Derkach, “Periscopic pumping systems for polarized proton target,” Proceedings of the International Conference on Electromagnetics in Advanced Applications. (ICEAA'99). Sept. 13–17, 1999, Torino, Italy, pp. 497–500.
3. V. N. Derkach, R. V. Golovashchenko, A. S. Plevako, “Investigation of field distribution in open resonators using three-coordinate scanner,” Proceeedings of the 12th International Conference "Microwave & Telecommunication Technology" (CriMiCo’2002), September 9-13, 2002. Sevastopol, Crimea, Ukraine, pp. 548–549.
DOI: http://dx.doi.org/10.1109/CRMICO.2002.1137350
4. V. N. Derkach, R. V. Golovashchenko, Ye. V. Goroshko, “Coupled disk dielectric resonators with whispering gallery modes in the millimeter-wave band.” Telecommunications and Radio Engineering, 2010, Vol. 69, No. 6, pp. 481–488.
DOI: http://dx.doi.org/10.1615/TelecomRadEng.v69.i6.20
5. V. N. Derkach, R. V. Golovashchenko, E. V. Goroshko, V. G. Korzh, “Millimeter waves controlled elements on the basis of disk dielectric resonators,” Proceedings of the 18th International Conference on Microwave Radar and Wireless Communications (MIKON’2010), Vilnius, Lithuania, 14-16 June 2010, pp. 384–387.
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5540627
6. V. N. Derkach, R. V. Golovashchenko, O. V. Goroshko, V. G. Korzh, S. V. Nedukh, O. S. Plevako, S. I. Tarapov, “Application of whispering gallery resonators for cryogenic measurements of low loss dielectrics at millimeter waves,” Proceedings of the 10th International Symposium on Microwave and Optical Technology, ISMOT-2005, Fukuoka Institute of Technology, Fukuoka, Japan, August 22-25, 2005, pp. 700–703.
7. R. V. Golovashchenko, O. V. Goroshko, A. V. Varavin, A. S. Plevako, V. N. Derkach, ”Hardware and software complex for mm-wave spectroscopic research,” Proceedings of the 16th International Crimean Conference “Microwave & Telecommunication Technology” (CriMiCo’2006), September 11-15, 2006, Sevastopol, Crimea, Ukraine, pp. 817–818.
DOI: http://dx.doi.org/10.1109/CRMICO.2006.256215

2. Dielectrometry of low-loss semiconductor and dielectric materials in the temperature range of 0.5 K < T < 300 K

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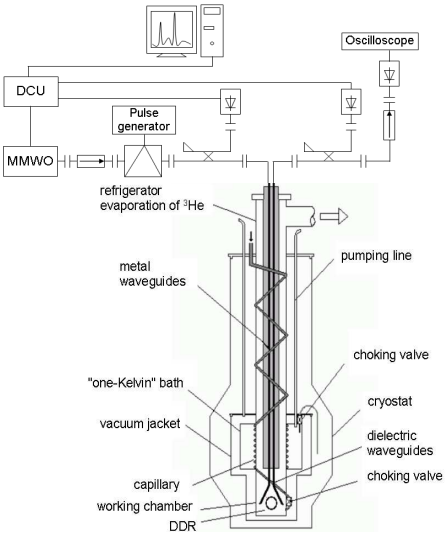
Methods and equipment

A cryogenic complex for radiospectroscopic measurements – cryodielectrometer “TORNADO” – is designed for low-temperature measurements of dielectric parameters of materials with low loss in the millimeter waveband and temperature range 0.5 – 300 K. Functionally cryodielectrometer is the constituent element of the scientific object “National Treasure of Ukraine”, http://www.ire.kharkov.ua/en/national-treasure.html



The parameters of the cryogenic radiospectrometer:

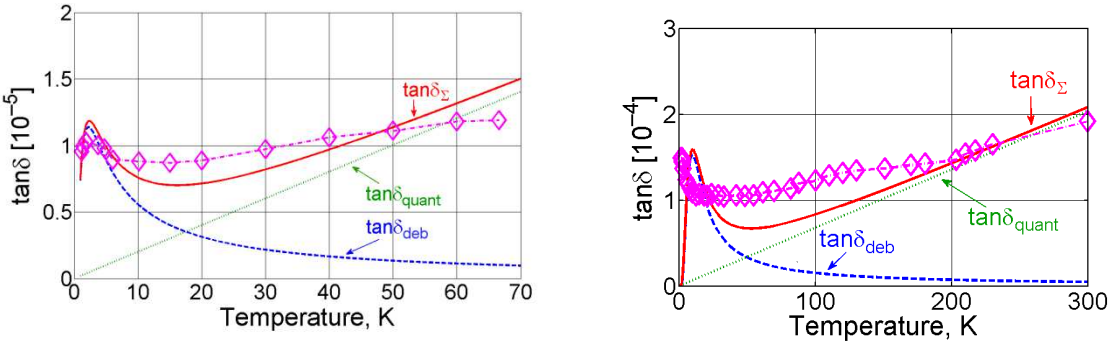
- frequency range – 60 GHz – 150 GHz;
- measurement technique – resonator technique (disk dielectric resonator (DDR)) with whispering gallery modes (WGM));
- temperature range – 0.8 K – 300 K (^{4}He), 0.5 – 300 K (^{3}He);
- cooling system – "Top-loading" refrigerator with circulation of ^{4}He or ^{3}He;
- volume of the working chamber – 50 cm^3.

Measuring and calibrating units of the radiospectrometer

The main results

2.1. The electrophysical parameters of such diamond-like materials as semiconductors: Si, Ge, GaP, InP, GaAs and other diamond-like materials are measured in wide frequency band (60 – 150 GHz) and temperature range (0.5 – 300 K) for the first time.

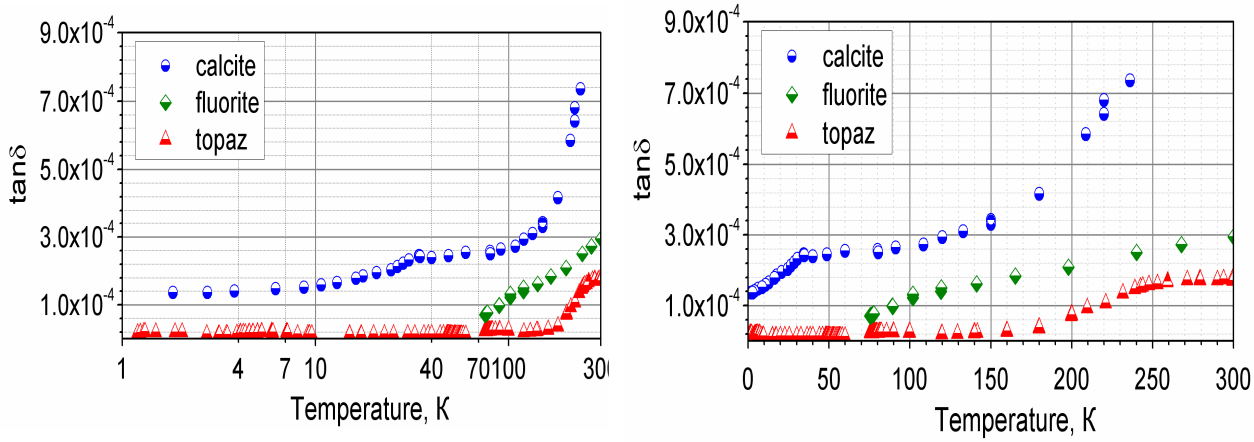
On the base of the obtained experimental data the analysis of loss mechanisms for some diamond-like structures is carried out and the contribution of the basic loss mechanisms is clarified in the microwave band. The approximation dependences ($\tan\delta_{\Sigma}$), which describes the experimentally registered losses (points-diamonds), caused by multiquantum mechanism of intrisic losses ($\tan\delta_{quant}$) and Debye mechanism of non-intrinsic losses ($\tan\delta_{deb}$) for samples of InP and CVD diamond.



a) b)

Dependence loss tangent of InP at the frequency f = 78 GHz (a) and CVD-diamond GPI RAS at the frequency f = 112 GHz (b) on the temperature

2.2. Temperature dependences of loss tangent of a number of natural radiotransparent materials (topaz, agate, chrysoprase, jadeite, rhodonite, calcite, fluorite, carnelian, chalcedony, etc.) is measured by using the technique of the disk dielectric resonator with whispering gallery modes. As it can be evident from the figure, these dependences are nonmonotonic for some minerals. Their behaviour is caused, probably, by competition of energy loss mechanisms, which is proper for composite dielectrics with a complex structure. The unique characteristics of topaz associated with low level of losses closed to loss in artificial crystal materials are demonstrated.



Temperature dependence of loss tangent of some low-loss natural minerals (experiment)

2.3. The interaction of electromagnetic fields with elementary excitations in superfluid helium is demonstrated by use of the designed disk dielectric resonators and by use of technique of measurement of the absorption of electromagnetic energy in the media surrounding the DDR [5,6].

The detailed presentation of the results is given in the publications:

1. V. N. Derkach, Yu. F. Filippov, A. S. Plevako, Yu. V. Prokopenko, T. A. Smirnova, “Determination of microwave parameters of isotropic mediums by using an open quasi-optical spherical resonator,” International Journal of Infrared and Millimeter Waves, 2004, Vol. 25, Issue 1, pp. 139–148.
   DOI: http://dx.doi.org/10.1023/B:IJIM.0000012769.99375.b6
2. V. N. Derkach, R. V. Golovashchenko, S. V. Nedukh, O. S. Plevako, S. I. Tarapov, “Using of the millimeter wave dielectrometer for study of liquid helium dynamic characteristics,” Proceedings of the 15th Int. Crimean Conference “Microwave & Telecommunication Technology” (CriMiCo’2005), September 12-16, 2005, Sevastopol, Crimea, Ukraine, pp. 836–837.
   URL: http://dx.doi.org/10.1109/CRMICO.2005.1565162

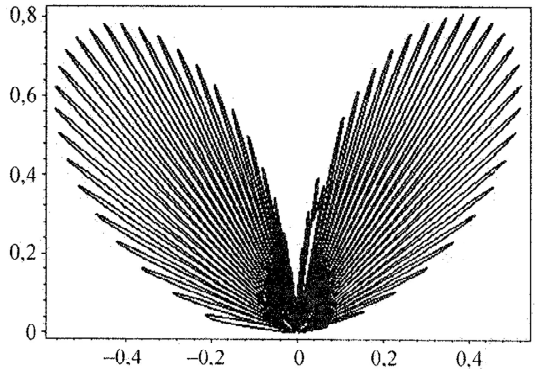
3. B. M. Garin, V. I. Polyakov, A. I. Rukovishnikov, L. A. Avdeeva, V. N. Derkach, V. V. Parshin, V. G. Ralchenko, “Dielectric loss and energy distribution of the shallow levels in CVD diamonds,” Diamond & Related Materials, 2006, Vol. 15, No. 11–12, pp. 1917–1920. DOI: http://dx.doi.org/10.1016/j.diamond.2006.08.023
4. V. N. Derkach, T. V. Bagmut, R. V. Golovashchenko, V. G. Korzh, S. V. Nedukh, S. I. Tarapov, “A circular-disk dielectric resonator for low-temperature magnetic resonance measurements at millimeter and sub-millimeter wavelengths,” Telecommunications and Radio Engineering, 2008, Vol. 67, No. 14, pp. 1239–1245. DOI: http://dx.doi.org/10.1615/TelecomRadEng.v67.i14.20
5. A. Rybalko, S. Rubets, E. Rudavskii, V. Tikhiy, S. Tarapov, R. Golovashchenko, V. Derkach, “Resonance absorption of microwaves in He II: Evidence for roton emission,” Physical Review B, 2007, Vol. 76, No. 14, paper 140503, 4 pages. DOI: http://dx.doi.org/10.1103/PhysRevB.76.140503
6. A. S. Rybalko, S. P. Rubets, É. Ya. Rudavskiĭ, V. A. Tikhiĭ, R. Golovashchenko, V. N. Derkach, S. I. Tarapov, “Interaction of microwaves with superfluid flow in HeII,” Low Temperature Physics, Vol. 34, No. 4–5, 2008, pp. 254–261. DOI: http://dx.doi.org/10.1063/1.2911649
7. A. S. Rybalko, S. P. Rubets, É. Ya. Rudavskiĭ, V. A. Tikhiĭ, R. Golovashchenko, V. N. Derkach, S. I. Tarapov, “Interaction of microwaves with superfluid flow in HeII,” Low Temperature Physics, 2008, Vol. 34, No. 4–5, pp. 254–261. DOI: http://dx.doi.org/10.1063/1.2911649
8. A. Rybalko, E. Rudavskii, S. Rubets, V. Tikhiy, V. Derkach, S. Tarapov, “Resonance microwave absorption in He II,” Journal of Low Temperature Physics, 2008, Vol. 150, No. 3–4, pp. 160–167. DOI: http://dx.doi.org/10.1007/s10909-007-9529-0
9. A. S. Rybalko, S. P. Rubets, É. Ya. Rudavskiĭ, V. A. Tikhiĭ, S. I. Tarapov, R. V. Golovashchenko, V. N. Derkach, “Microwave experiments in He II. New features of undamped superfluid flows,” Low Temperature Physics, 2008, Vol. 34, No. 7, pp. 497–502. DOI: http://dx.doi.org/10.1063/1.2957000
10. A. S. Rybalko, S. P. Rubets, E. Ya. Rudavskii, V. A. Tikhiy, Yu. M. Poluectov, R. V. Golovachenko, V. N. Derkach, S. I. Tarapov, O. V. Usatenko, “Resonance excitation of single rotons in He II by an electromagnetic wave. Spectral line shape,” Low Temperature Physics, 2009, Vol. 35, No. 11, pp. 837–842. DOI: http://dx.doi.org/10.1063/1.3266909
11. A. Rybalko, S. Rubets, E. Rudavskii, V. Tikhiy, Y. Poluectov, V. Derkach, R. Golovashchenko, S. Tarapov, O. Usatenko, “Microwave spectroscopy of condensed helium at the roton frequency,” Journal of Low Temperature Physics, 2010, Vol. 158, No. 1–2, pp. 244–249. DOI: http://dx.doi.org/10.1007/s10909-009-0025-6
12. V. N. Derkach, R. V. Golovashchenko, A. S. Plevako, “Disk resonators for investigation of low-loss media characteristics in the millimeter waveband,” Proceedings of the 23rd International Crimean Conference “Microwave & Telecommunication Technology” (CriMiCo’2013), September 8–14, 2013, Sevastopol, Crimea, Ukraine, 2013, pp. 992–993. URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6653160
13. R. V. Golovashchenko, V. N. Derkach, S. I. Tarapov, “Microwave loss in low-absorption diamond-like materials at 1 K < T < 300 K. The phenomenological simulation,” Telecommunications and Radio Engineering, Vol. 75, Issue 3, 2016, pp. 215–227. DOI: http://dx.doi.org/10.1615/TelecomRadEng.v75.i3.30

3. Experimental study of the spectral characteristics of fields of diffraction by fractal and resonance structures

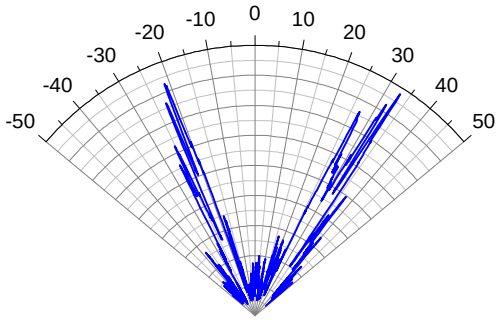
Responsible: V. N. Derkach (Ph.D. in Phys. and Math.), A. N. Salogub, Ye. M. Ostryzhnyi

Results of investigation

3.1. The theoretical calculation of the parameters of pre-fractal structures is carried out on the base of mathematical theory of self-similar fractals with use of the integral equation method, Carleman-Vekua numerical-analytical regularization method and direct method of mechanical quadratures. Pre-fractal diffraction gratings of the second stage of the generation are investigated.



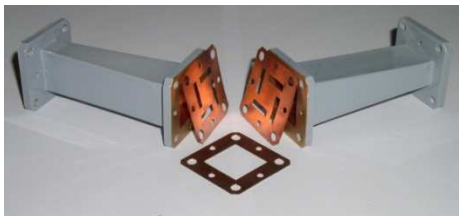
Calculation

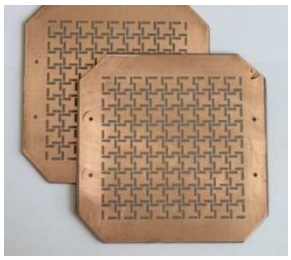


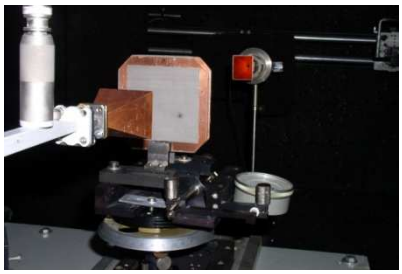
Experiment

The experimentally measured radiation patterns of the transmitted E-polarized electromagnetic wave is qualitatively consistent with the results obtained theoretically.

3.2. The efficient compact polarizers of electromagnetic radiation for gigahertz and terahertz frequencies that can rotate the angle of polarization in the frequency bandwidth of 10% from the center frequency on the arbitrary predetermined angle with losses of electromagnetic energy not more than 0.1 dB are designed and developed on the basis of theoretical studies in the Department of computational electromagnetics and our experimental investigation. It is shown that the composite plane-chiral two-slot irises (CPCI) (for a waveguide) and lattices of plane-chiral two-slot irises (for beam guide and free space) demonstrate the properties of a giant "optical activity" and lead to a rotation of the polarization plane without change of ellipticity.







Electric- and magneto-controllable polarizers as well as frequency selective filters and polarization filters and other devices can be made on the base of CPCI. The gaps between CPCI can be filled by ferrite, ferroelectric, piezoelectric or multiferroic. Such devices may find wide use in antenna technique, telecommunication and microwave techniques. It is also shown that CPCI lattices possess focusing properties and can be used as flat lenses.

The detailed presentation of the results is given in the publications:

1. V. N. Derkach, G. I. Koshovyi, O. M. Salogub, “Millimeter-wave scattering by prefractal diffraction gratings,” Proceedings of the 22nd International Crimean Conference “Microwave and Telecommunication Technology” (CriMiCo’2012), Sevastopol, Crimea, Ukraine, 2012, pp. 833–834.
   URL: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6336212
2. V. Derkach, A. Kirilenko, A. Salogub, S. Prikolotin, N. Kolmakova, Ye. Ostrizhnyi, “Gigant optical activity in artificial plane-chiral structures,” Proceedings of the 2013 International Kharkov Symposium on Physics and Engineering of Microwaves, Millimeter and Submillimeter Waves (MSMW’2013), 21-26 June 2010, Kharkov, Ukraine, paper W-33.
   DOI: http://dx.doi.org/10.1109/MSMW.2010.5546039
3. V. N. Derkach, A. A. Kirilenko, A. N. Salogub, S. A. Prikolotin, N. G. Kolmakova, Ye. M. Ostrizhnyi, “Polarization conversion by bilayer chiral structure with giant optical activity,” Proceedings of the 23rd International Crimean Conference “Microwave and Telecommunication Technology” (CriMiCo’2013), Sevastopol, Crimea, Ukraine, 2013, pp. 994–995.
   URL: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6653161
4. V. N. Derkach, A. A. Kirilenko, A. O. Perov, S. A. Prikolotin, A. M. Salogub, “A giant 'optical activity' of composite plane-chiral irises at microwaves,” Telecommunications and Radio Engineering, 2014, Vol. 73, No. 14, pp. 1219–1227.
   DOI: http://dx.doi.org/10.1615/TelecomRedEng.v73.i14.10
5. A. A. Kirilenko, N. G. Kolmakova (Don), A. O. Perov, S. A. Prikolotin, V. N. Derkach, “Natural oscillations providing 90° polarization plane rotation by planar chiral double-slot irises,” Radioelectronics and Communications Systems, 2014, Vol. 57, No. 12, pp. 521–530.
   DOI: http://dx.doi.org/10.3103/S0735272714120012
6. A. O. Perov, A. A. Kirilenko, V. N. Derkach, A. N. Salogub, “Double screen system with circular under-cuttof holes as quasioptical polarizer,” Radiofizika i Elektronika, 2014, Vol. 6(20), No. 3, pp. 3–10. (in Russian).
   URL: http://nbuv.gov.ua/UJRN/rphre_2015_6(20)_3_3
7. N. Kolmakova, S. Prikolotin, A. Perov, V. Derkach, A. Kirilenko, “Polarization plane rotation by arbitrary angle using D4 symmetrical structures,” IEEE Transactions on Microwave Theory and Techniques, 2016, Vol. 64, No. 2, pp. 429–435.
   DOI: http://dx.doi.org/10.1109/TMTT.2015.2509966