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Наноскопия со сверхразрешением

БАЗИС
Фонд развития теоретической физики и математики

Летняя школа Фонда «БАЗИС» — 31.07.2024

«Современные проблемы физики конденсированного состояния»

Как лауреаты Нобелевской премии применяют оборудование ZEISS

https://zeiss-solutions.ru/press/news/nobel/

1905 Роберт Кох / Robert Koch
Лауреат Нобелевской премии по медицине

Роберт Кох в 1880-х гг. обнаружил палочки, которые вызывают туберкулез и холеру. В письме Карлу Цейсу (Carl Zeiss) он написал: **«По большей части своим успехом я обязан вашим превосходным микроскопам»**. В 1904 году в качестве подарка он получил десятитысячный объектив ZEISS с гомогенной иммерсией.

1906
Сантьяго Рамон-и-Кахаль / Santiago Ramón y Cajal и Камилло Гольджи / Camillo Golgi
Лауреаты Нобелевской премии по физиологии и медицине

1911
Альвар Гульстранд / Allvar Gullstrand
Лауреат Нобелевской премии по физиологии и медицине

1925
Ричард Жигмонди / Richard Zsigmondy
Лауреат Нобелевской премии по химии

1953
Фриц Цернике / Frits Zernike
Лауреат Нобелевской премии по физике

1967
Манфред Эйген / Manfred Eigen
Лауреат Нобелевской премии по химии

1991
Эрвин Неер / Erwin Neher и Берт Сакман / Bert Sakmann
Лауреаты Нобелевской премии по медицине

1995
Кристиана Нюсляйн-Фольхард / Christiane Nüsslein-Volhard
Лауреат Нобелевской премии по физиологии и медицине

1999
Гюнтер Блобел / Günter Blobel
Лауреат Нобелевской премии по физиологии и медицине

1999
Ахмед Зевайл / Ahmed H. Zewail
Лауреат Нобелевской премии по химии

2001
Эрик Корнелл / Eric A. Cornell
Лауреат Нобелевской премии по физике

2001
Сэр Пол Нерс / Paul M. Nurse, Леланд Хартвелл / Leland H. Hartwell и Тимоти Хант / Timothy Hunt
Лауреаты Нобелевской премии по физиологии и медицине

2002
Сидней Бреннер / Sydney Brenner, Роберт Хорвиц / H. Robert Horvitz и Джон Салстон / John E. Sulston
Лауреаты Нобелевской премии по химии

2006
Крейг Мелло / Craig Mello и Эндрю Файер / Andrew Fire
Лауреаты Нобелевской премии по физиологии и медицине

2008
Харальд цур Хаузен / Harald zur Hausen
Лауреат Нобелевской премии по физиологии и медицине

2008
Осаму Симомура / Osamu Shimomura, Мартин Чэлфи / Martin Chalfie и Роджер Тсиен / Roger Tsien
Лауреаты Нобелевской премии по химии

2010
Андрей Гейм и Константин Новоселов
Лауреаты Нобелевской премии по физике

2011
Дан Шехтман / Dan Shechtman
Лауреат Нобелевской премии по химии

2012
Сэр Джон Гёрдон / John B. Gurdon и Шинья Яманака / Shinya Yamanaka
Лауреаты Нобелевской премии по физиологии и медицине

2014

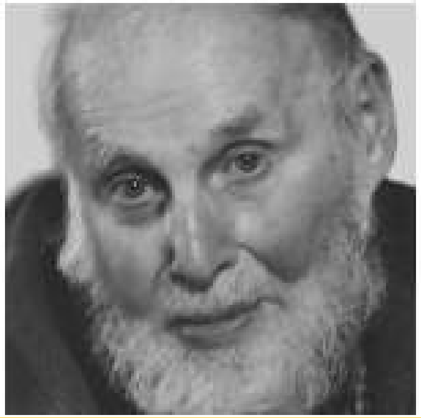
Эрик Бетциг / Eric Betzig, Штефан Хелль / Stefan W. Hell и Уильям Мернер / William E. Moerner

Лауреаты Нобелевской премии по химии

2014

Джон О'Киф / John O'Keefe, Мэй-Бритт Мозер / May-Britt Moser и Эдвард Мозер / Edvard I. Moser

Лауреаты Нобелевской премии по физиологии и медицине



2018

Артур Эшкин / Arthur Ashkin, Жерар Муру / Gérard Mourou, Донна Стрикленд / Donna Strickland

Лауреаты Нобелевской премии по физике

Был ли телескоп у Птолемея?

Птолемей Клавдий (около 100 - около 170)

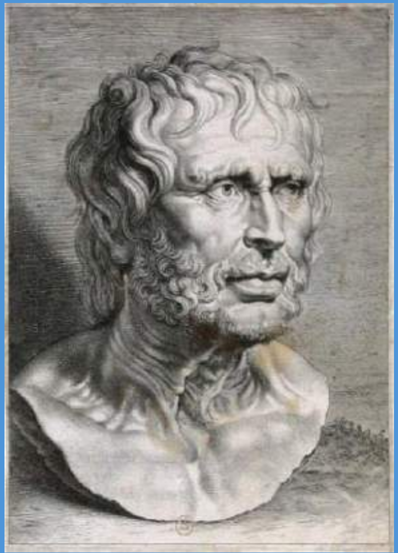
The Nimrud lens 700 BC

Возраст линз, найденных при раскопках Трои, датируют примерно 2500 годом до нашей эры.

Был ли микроскоп в древнем Вавилоне?

XXII—XXI век до н. э.

Glass technology was developed about 5000 years ago.



Seneca
4 BC – AD 65

Seneca, Nero's teacher, reported on the magnifying properties of glass spheres. By the way, Nero himself watched gladiator fights through a specially ground emerald.

The ancient Romans and Greeks filled glass spheres with water to make lenses.

Pliny the Elder reported on incendiary action of glass spheres.

Pliny the Elder

- AD 23–79

Очки были изобретены, по-видимому, в Италии в XIII веке. Предполагаемый год изобретения — 1284, а создателем первых очков считается Сальвино Д'Армате (итал.),

Он сунул руку в рясу и извлек на свет свои глазные стекла, при виде которых наш собеседник остолбенел. Почти мгновенно глазной снаряд оказался в руках Николая. «Oculi de vitro cum capsula (стёкла в металлической оправе)! – воскликнул он. – Я слышал о подобных в Пизе».

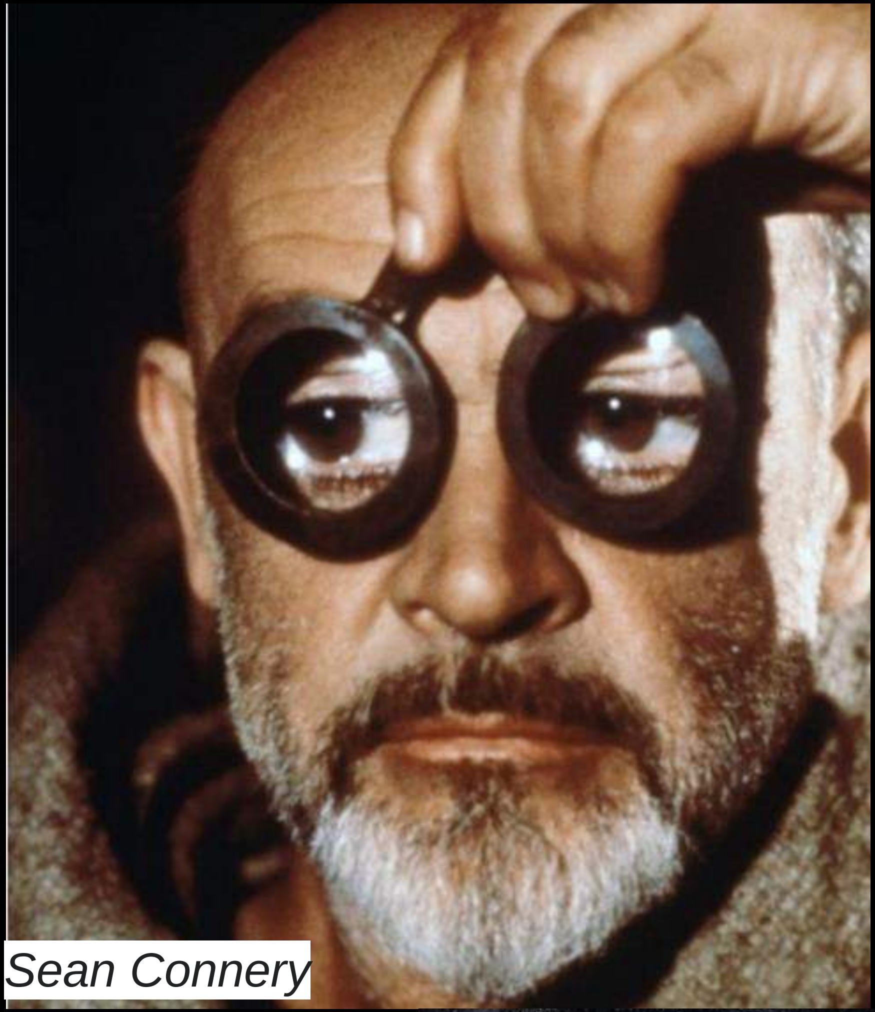
«Изготовление их трудоемко, – сказал Вильгельм, – и требуются очень опытные стекольщики. Долгое, кропотливое дело. Десять лет назад одна пара таких вот vitrei ab oculis ad legendum (стёкол для чтения) шла с торга в Болонье за шесть сольдов. А мне подарил такую же пару знаменитый мастер Сальвин из Армати, уже больше десяти лет назад, и все эти годы я берег их как зеницу ока… Впрочем, теперь они и впрямь у меня вместо зеницы».

«Может быть, ты как-нибудь на днях сможешь ненадолго их мне одолжить? Очень хочется понять устройство… Попробовать сделать похожее…» – сказал Николай.

«Конечно, дам, – отвечал Вильгельм. – Но имей в виду, что толщина стекол для каждых глаз требуется особая. Обычно берут много пар обточенных стекол, и пробуют все по очереди, пока не найдут подходящие».

«Чудеса! – не утихал Николай. – Кое-кто, конечно, заподозрил бы тут сделку с дьяволом…».

Умберто Эко «Имя розы»



Sean Connery

Джакомо Баттиато

«Вот уже минуло 20 лет, как открыто одно из самых необходимых искусств в мире, призванных улучшить зрение. Как мало времени прошло с тех пор, как было изобретено новое, никогда не существовавшее искусство. Я видел человека, первым создавшего очки, и я беседовал с ним».

Из дневника Джордано да Риальто, хранителя библиотеки монастыря Св. Екатерины в Венеции. 1305 год.

Santa Caterina, Venice

In the 1970s the church was devastated by a fire during restoration works, destroying the rest of its works of art.

Paolo Veronese, *Mystic Marriage of Saint Catherine*, 1571, Gallerie dell'Accademia, Venice

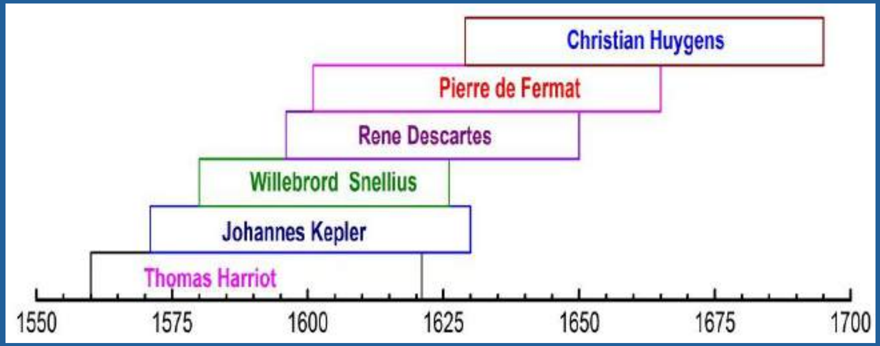
Tintoretto *Мученичество св. Екатерины*

Archimedes, Ptolemy and apparently all antique physics knew the effect of light refraction.

However, to establish the correct law of light refraction was not easy. This law, in its correct form, was firstly discovered by the scientist Ibn Sahl at the court of Baghdad in 984 and later rediscovered several times by Thomas Harriot in 1602, Johannes Kepler in 1604, Willebrord Snellius (Snell) in 1621 and Rene Descartes in 1637. In 1662 Pierre de Fermat showed that this law follows from Fermat's principle, which states that light follows the path that minimizes the time. In 1678 Christiaan Huygens showed how Snell's law of sines could be explained using the wave nature of light and Huygens–Fresnel principle.

Archimedes of Syracuse
287– 212 BC

Claudius Ptolemy
AD 100 – 170



In 1621 Snell found the law of the light refraction

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Ayla ibn Sahl 940 – 1000 Iraq

Thomas Harriot 1560 – 1621 England

Johannes Kepler 1571 – 1630 Germany

Willebrord Snellius 1580 – 1626 Dutch

Rene Descartes 1596 – 1650 France

Pierre de Fermat 1601-1665 France

Christian Huygens 1629 - 1695 Dutch

Photonic nanojet - a discovery that did not happen 400 years ago

Pliny the Elder
AD 23–79

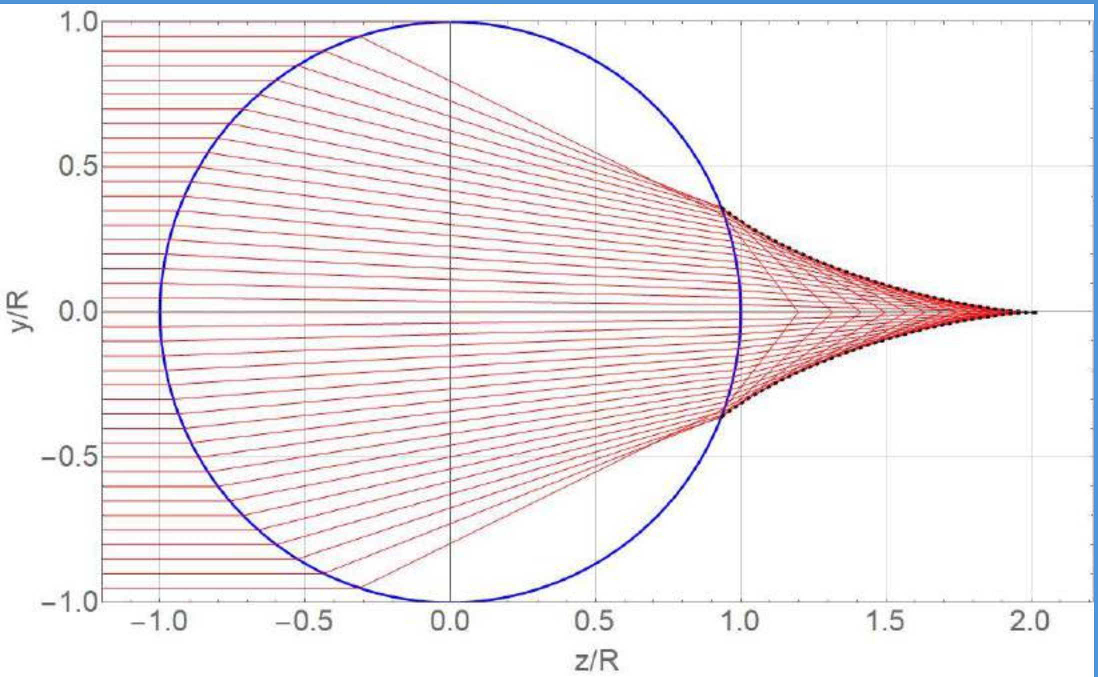
In 1604 Kepler introduced the meaning of focus and explained the principles of pinhole cameras. In his book published in 1611 he described light refraction and the concept of the optical image. He yielded also the general theory of lenses. Kepler was familiar with the law of sines and knew the trigonometric tables of Rheticus, published in 1551, as well as Napier's tables of logarithms. It was not difficult for Kepler and Snell to plot the ray tracing with transparent sphere and cylinder to see the effect of light focusing and explain how the fire glass of Pliny the Elder works.

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$x_c = \left[1 - \frac{1}{2}\frac{\sqrt{n^2 - 1 + \cos^2\varphi} - 2\cos\varphi}{\sqrt{n^2 - 1 + \cos^2\varphi} - \cos\varphi}\cos\varphi\right]\cos\psi$$

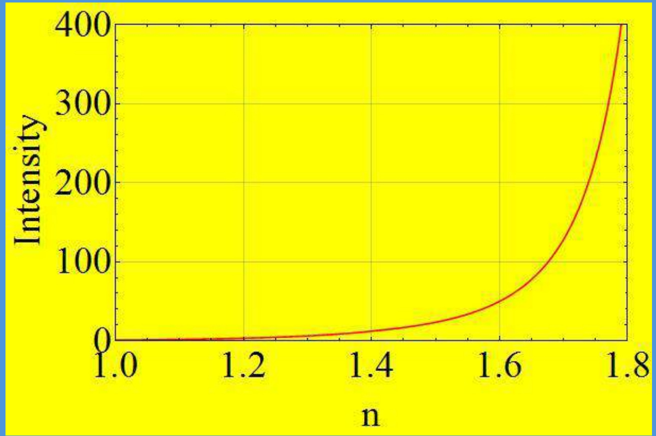
$$y_c = \sec\psi \sin\varphi + x_c \tan\psi,$$

$$\psi = 2\left[\varphi - \arcsin\left(\frac{\sin\varphi}{n}\right)\right].$$



Ray tracing for the drop of water, *n* = 1.33

The singularity point $x_s = x_c\big|_{\varphi\to 0} = \dfrac{n}{2(n-1)}$



N. Arnold, Appl. Surf. Sci. 208, 15 (2003)

$$\frac{E^2}{E_0^2} \approx \frac{27n^4}{(4 - n^2)^3}$$

At the approximation of geometrical optics effect does not depend on the particle size.

Ernst Abbe
1840 –1905

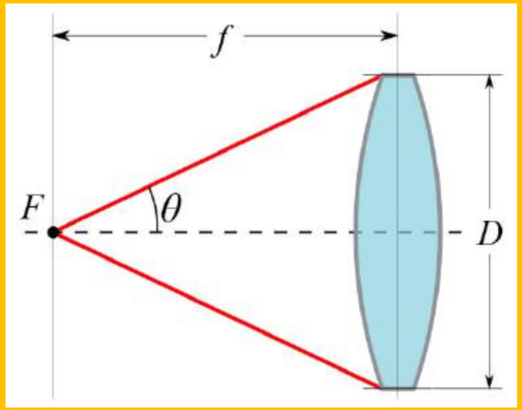
DIFFRACTION LIMIT

The resolution limit of the microscope $d = \frac{\lambda}{2\,NA}$ (1873)

Helmholtz states this formula was first derived by Lagrange

$$\text{NA} = n \sin\theta = n \sin[arc\,tan\,(\frac{D}{2f})] \approx n\frac{D}{2f}$$

In 1866, Abbe became a research director at the [Zeiss Optical Works]



Joseph-Louis Lagrange
1736-1813

$d = K\frac{\lambda}{NA}$, K = 0.5 (Abbe), K = 0.473 (Sparrow), K = 0.515 (Houston), K = 0.61 (Rayleigh)

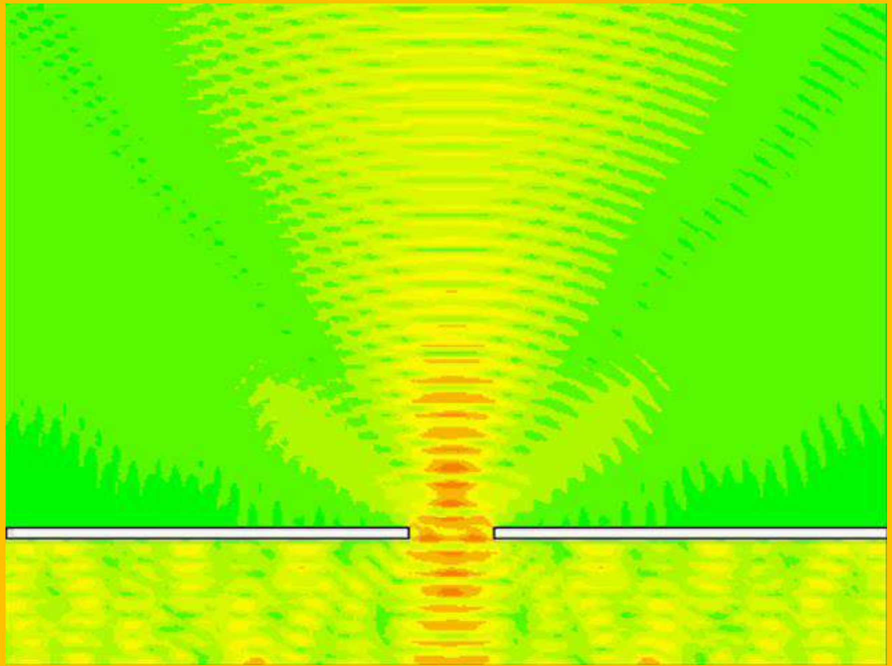
Heisenberg uncertainty principle $\Delta x\,\Delta p_x \sim \hbar.$ $p = n\hbar k,$ $k = \omega/c$ $\Delta p \sim p,$ $\Delta x \sim \lambda/(2n)$

The physical reason for diffraction limit is related to **loss of evanescent waves** in far-field.

$$\Delta A + k^2 A = 0, \quad A = A(x, y, z)$$

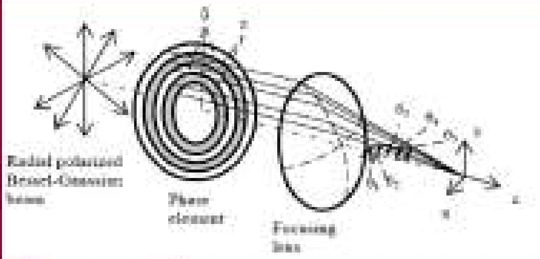
$$A_k = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} A(x,y,0)\exp\left[-ik_x x - ik_y y\right]dx\,dy$$

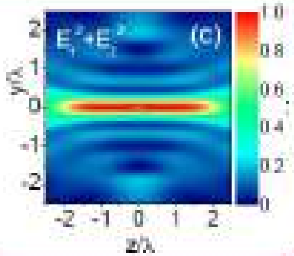
$$A(x,y,z) = \left(\frac{1}{2\pi}\right)^2 \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} A_k \exp\left[ik_x x + ik_y y + ik_z z\right]dk_x\,dk_y$$



1 Sub-diffractive optics, radially polarized light, Bessel-Gaussian beams, etc.

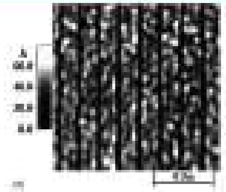
Wang H. F. et al, Nature Photonics 2, 501 (2008)





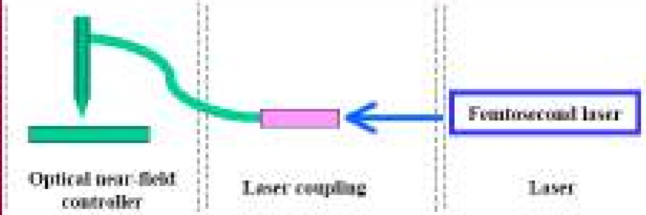
2 Field-enhancement by laser illuminated tip

Wang Z. B. et al, Appl. Phys. A 89, 363 (2007)



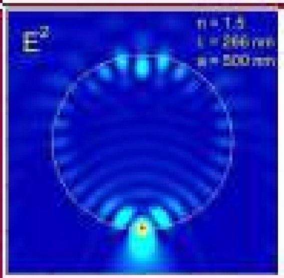
3 SNOM with femtosecond lasers

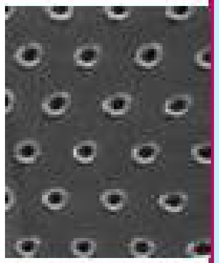
Wang W. J. et al, Proc. SPIE 5069, 330 (2003)



4 Optical resonances and near-field effects with transparent particles

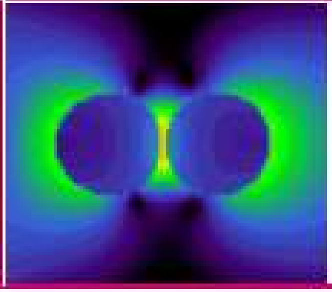
Luk'yanchuk B. S. et al, Proc. SPIE 4065, 576 (2000)

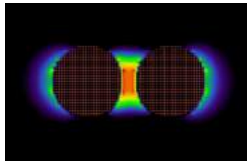


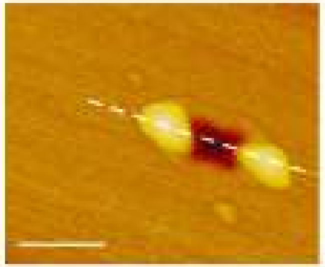


5 Plasmonic nanostructures

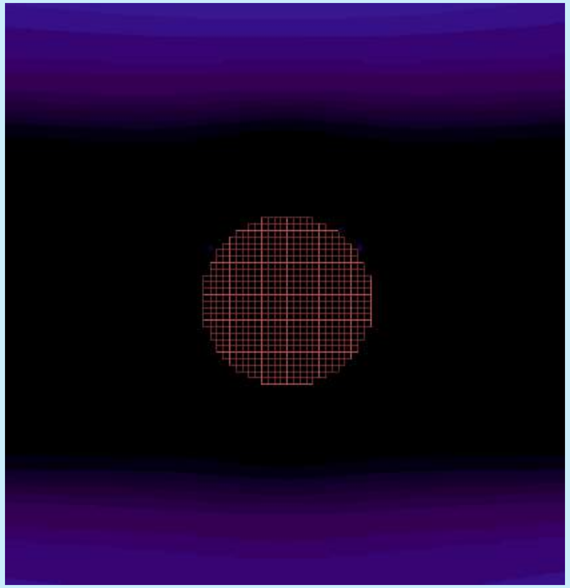
Eversole D. et al, Applied Physics A 89, 283-291 (2007)







Metallic particle with surface plasmon resonance



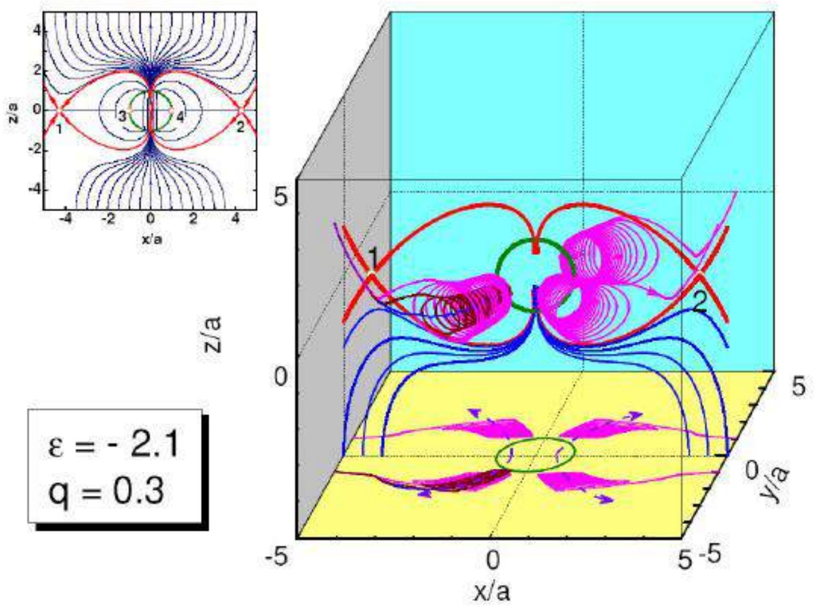


Fig. 3. Poynting vector lines for non-dissipative case around the spherical particle (incident plane wave comes from $z = -\infty$). Left insert shows 2D field in xz plane. Points 1 and 2 are saddles. Thick red lines indicate the separatrixes in xz-plane. Field lines in 2D picture demonstrate circular energy flows around centers (points 3 and 4). In 3D plot one can see the energy flow outward the particle (helicoidally shaped fields lines). It illustrates the radiative losses of energy, general directions of which are shown by arrows on the bottom xy projection plane.

Wang Z. B., Luk\`yanchuk B. S., Hong M. H., Lin Y., Chong T. C.
Energy flows around a small particle investigated by classical Mie theory
Phys. Rev. B. **70**, issue 3, 032427 (2004)

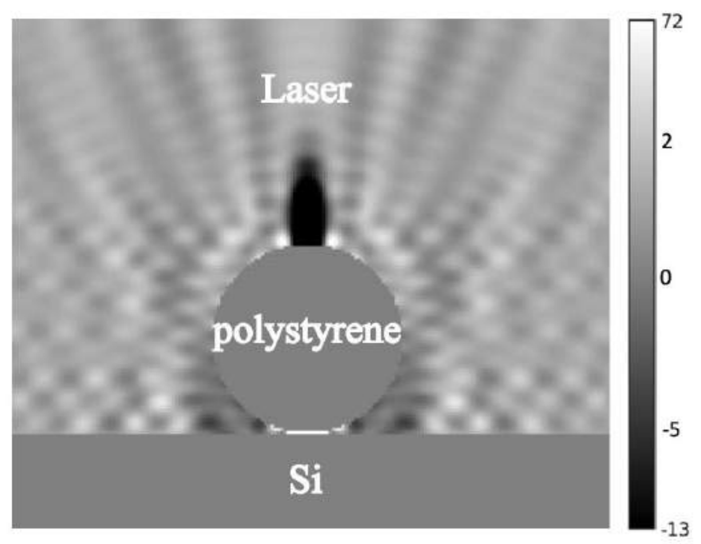
Tribelsky M.I., Luk'yanchuk B. S.
Anomalous light scattering by small particles
Physical Review Letters, vol. **97**, Issue 26, 263902 (2006)

Luk\`yanchuk B.S., Tribelsky M. I., Ternovsky V.
Light scattering at nanoparticles close to plasmon resonance frequencies
Journal of Optical Technology, vol. **73**, 371 (2006)

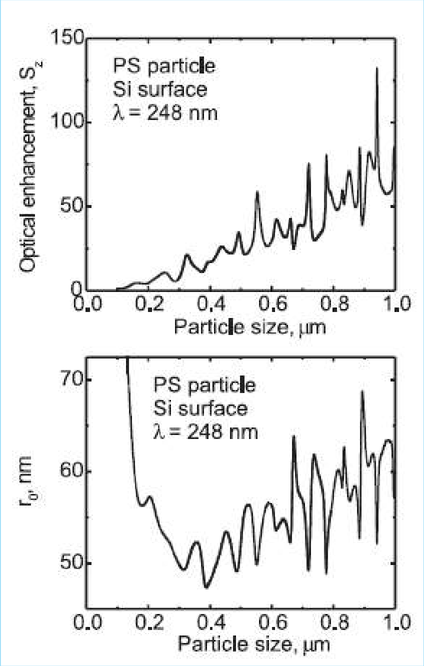
Luk\`yanchuk B. S., Wang Z. B., Hong M. H., Chong T. C., Ternovsky V., Tribelsky M.
Light scattering by nanoparticles and nanowires near plasmon resonance frequency
Journal of Physics: Conference series, Vol. 59, No. 1, pp. 234-239 (2007)

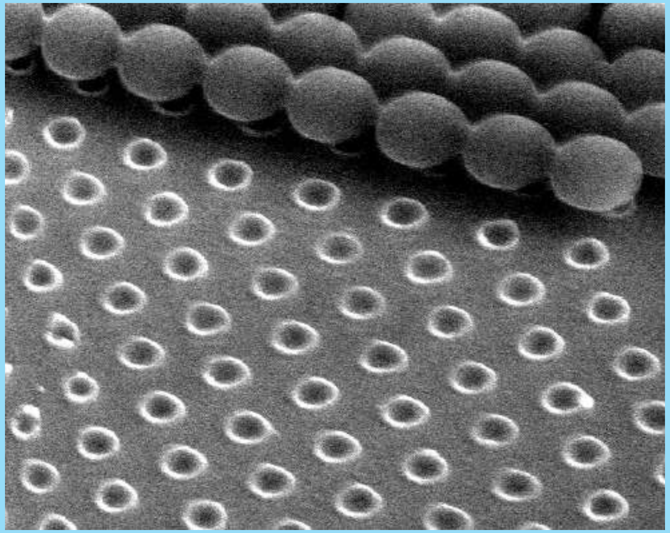
Eversole D., Luk'yanchuk B., Ben-Yakar A.
Plasmonic Laser Nanoablation of Silicon by the Scattering of Ultrafast Pulses near Gold Nanospheres
Applied Physics A, vol. **89**, issue 2, pp. 283-291 (2007)

Near field effects are based on the Mie theory and "Particle on surface theory

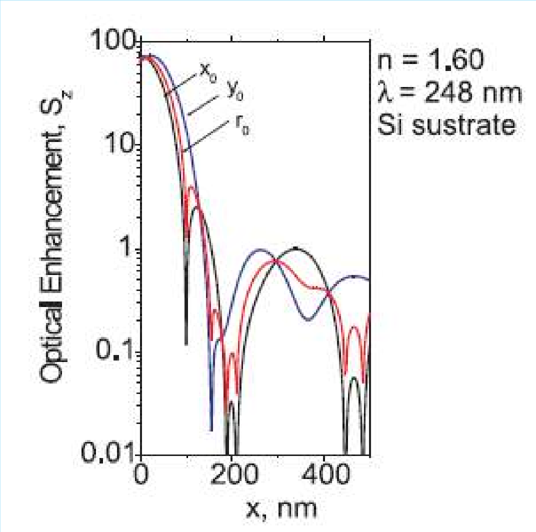


B. Luk`yanchuk et al.
Appl. Phys. A **79**, 747 (2004)

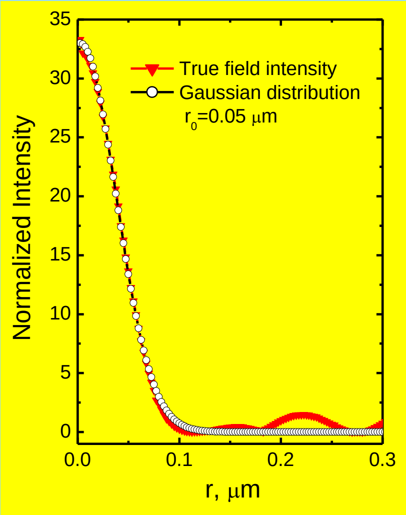


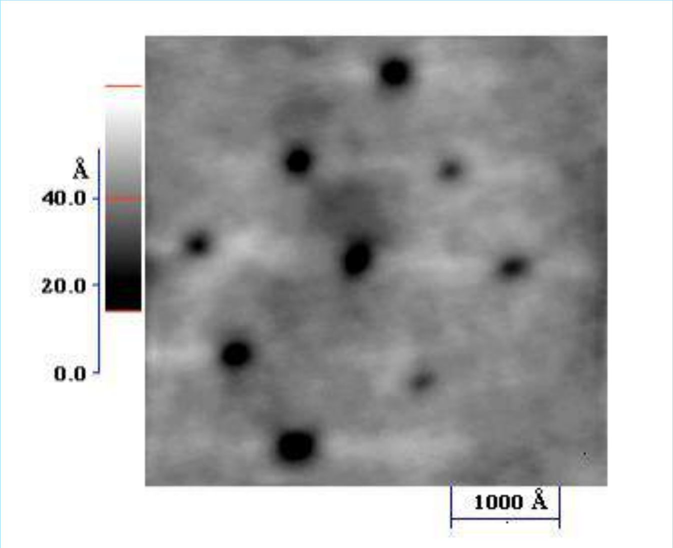


200 nm holes in Si: H.-J. Münzer et al.,
J. of Microscopy 202, 129 (2001)

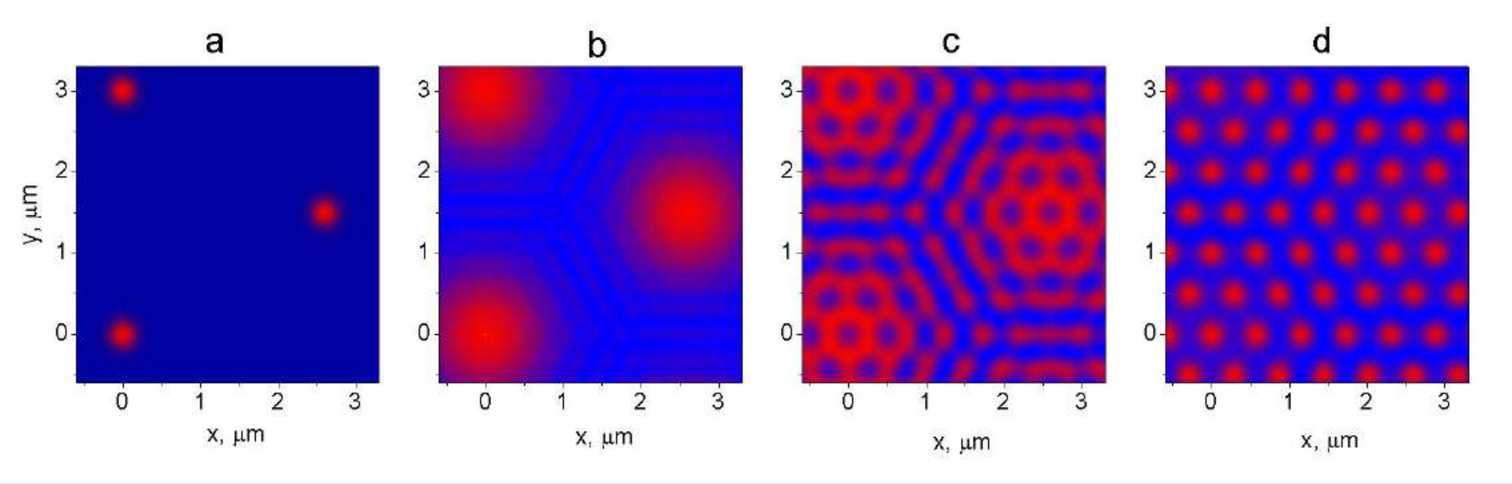


Distribution of the field enhancement factor Sz along *x* and *y* axes and the averaged distribution for polystyrene particle with size 2*a* = 1 μm on Si substrate

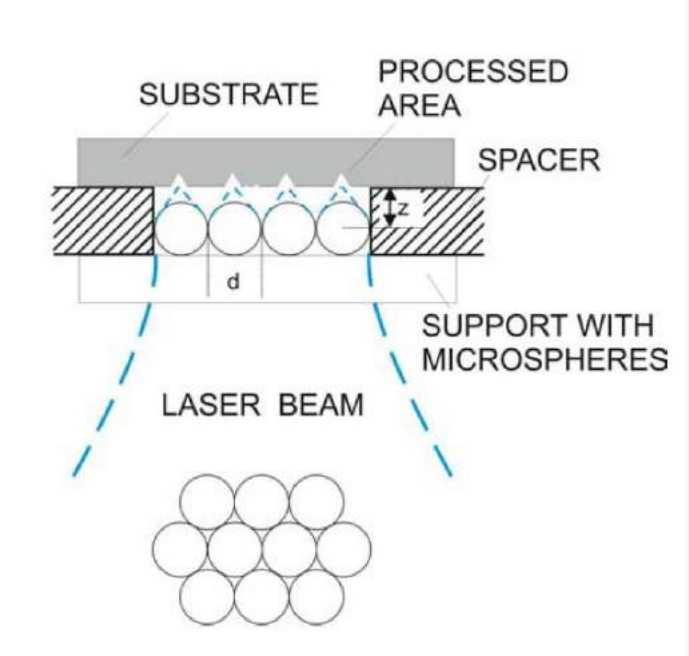


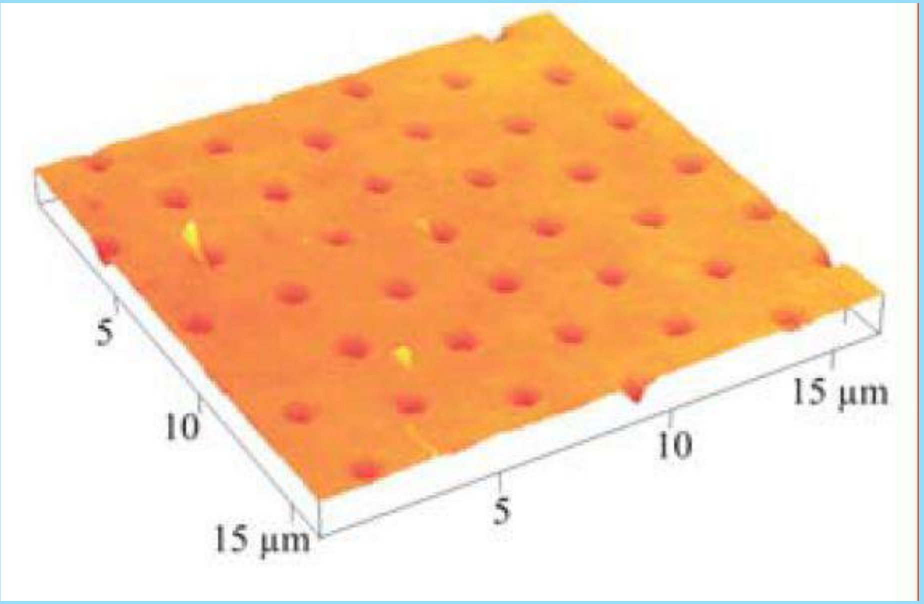


30 nm nanoholes in Al: Huang S. M., et al.,
J. Appl. Phys. **92**, 2495 (2002)



Interference pattern generated by superposition of three laser beams, spaced by distance *d* = 3 μm. The wavelength employed is λ *= 248 nm and the Rayleigh length* z_R *= 3* λ*. a) Intensity distribution within the focal plane; b) Intensity image in the plane situated on the distance z* = 3.47 μm *from the focal plane; c) the same with z* = 5.08 μm *and d) z* = 5.96 μ*m.*

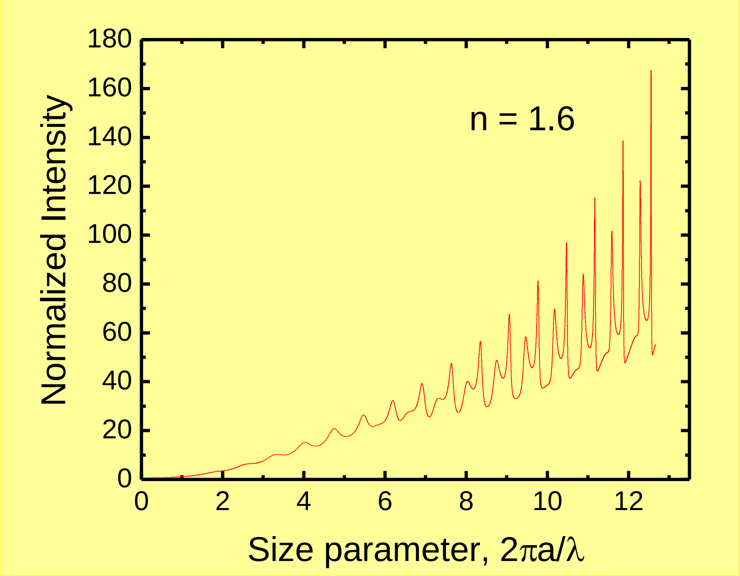


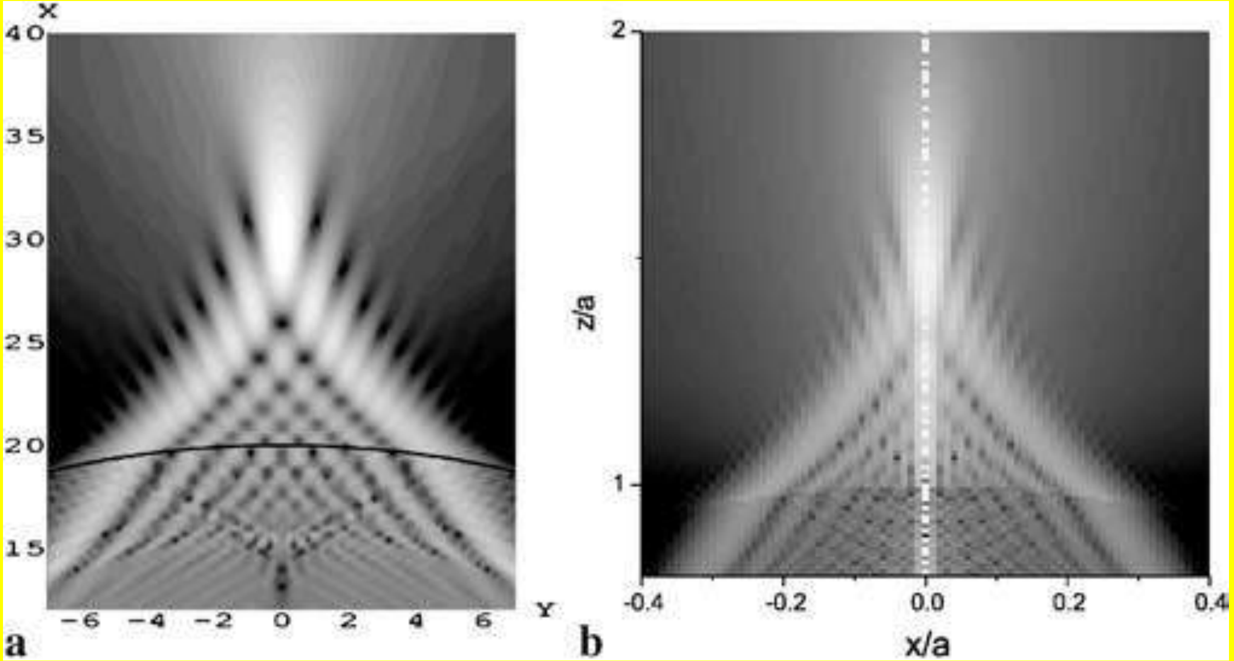


D. Bäuerle at al, Lambda Highlights, No. **60**, July 2002

Scattering effects at big size parameters

Optical resonances





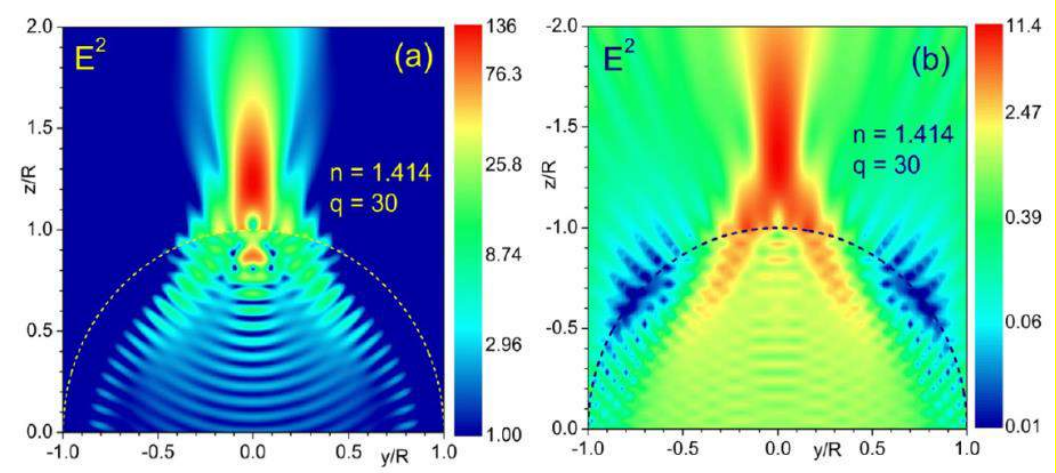
The caustic structure
B. Luk`yanchuk, N. Arnold…
Appl. Phys. A **79**, 747 (2004)

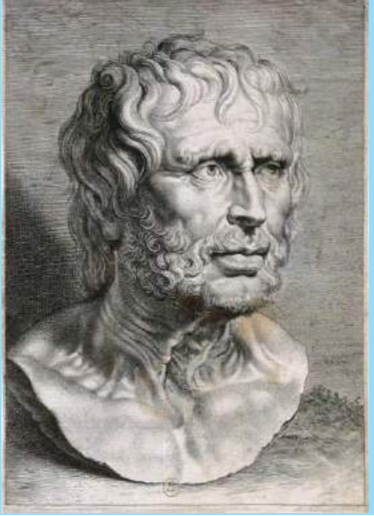
Distribution of the intensity within the caustic of the particle with the refractive index *n* =1.41 and the radius of *a* = 30*λ*. a Diffraction pattern for cylindrical symmetry; b diffraction pattern for spherical particle, calculated by the Mie theory

Pearcey function

$$\Psi\,(x, z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} ds\ \exp\left[i\left(\frac{s^4}{4} + \frac{s^2}{2}z + sx\right)\right],$$

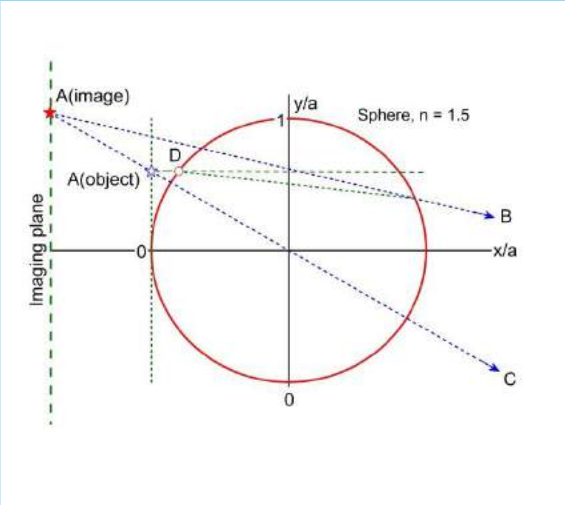
J. Kofler, N. Arnold, Phys. Rev. B **73**, 235401 (2006)



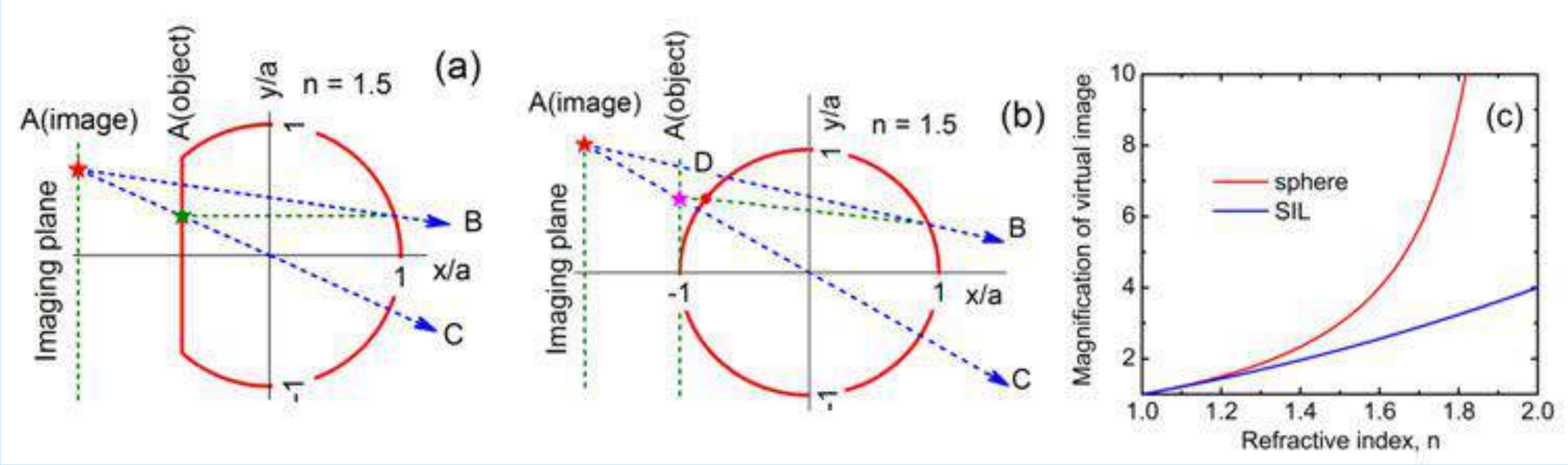


Seneca 4 BC – AD 65

Virtual image with transparent particle



Antonie van Leeuwenhoek
1632 – 1723



(a) solid immersion lens and (b) with spherical particle. The thickness of the SIL is $H = a\left(1 + n^{-1}\right)$

Magnification of the virtual image

$$M_{SIL} \approx n^2 \qquad M_{sphere} \approx n/(2-n).$$

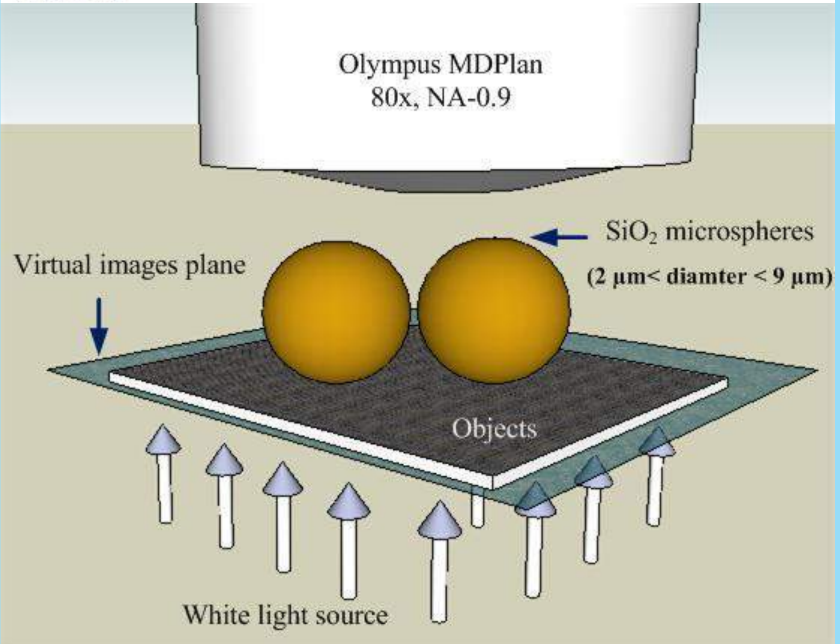
Микроскоп Левенгука
с увеличением до 300x.

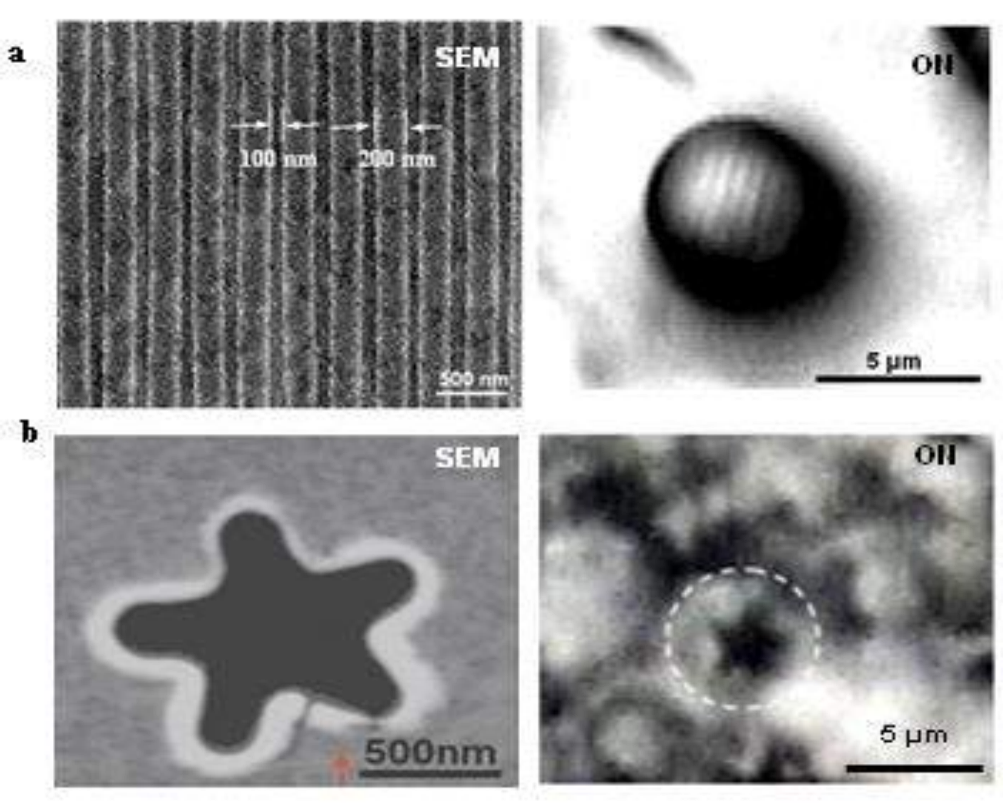
ARTICLE

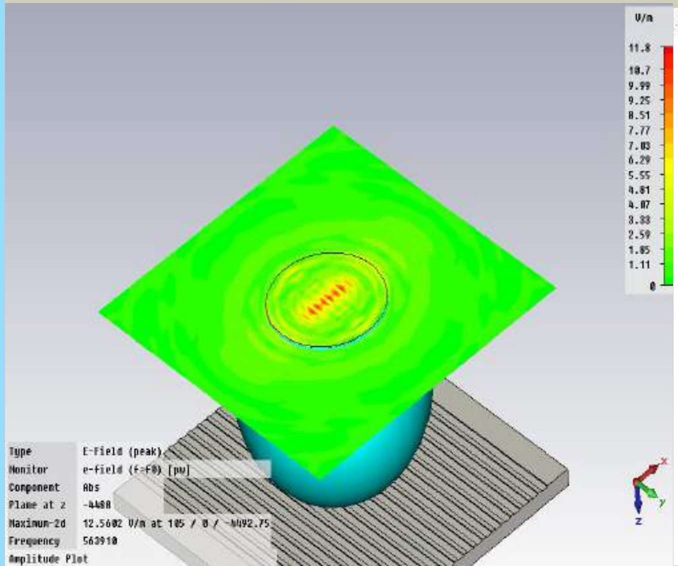
Received 16 Aug 2010 | Accepted 26 Jan 2011 | Published 1 Mar 2011 DOI: 10.1038/ncomms1211

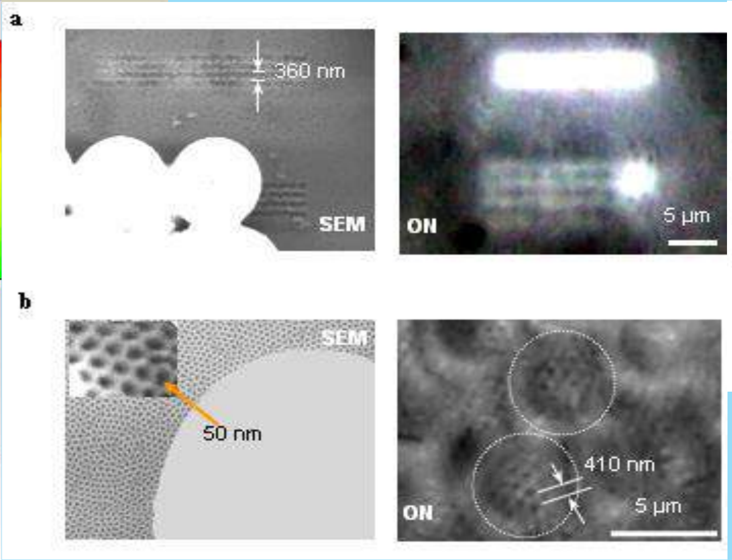
Optical virtual imaging at 50 nm lateral resolution with a white-light nanoscope

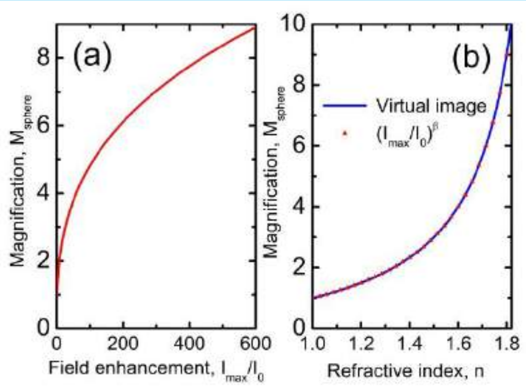
Zengbo Wang[1], Wei Guo[1,2], Lin Li[1], Boris Luk'yanchuk[3], Ashfaq Khan[1], Zhu Liu[2], Zaichun Chen[3,4] & Minghui Hong[3,4]











$$M_{sphere} \approx (I_{max}/I_0)^{\beta}$$

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1 March 2011 Last updated at 18:38 GMT

Microscope with 50-nanometre resolution demonstrated

By Jason Palmer
Science and technology reporter, BBC News

THE INDEPENDENT

Breaking News
Online Newspaper

ABC News

Daily Mail

THE STRAITS TIMES. A SINGAPORE PRESS HOLDINGS WEBSITE
BREAKING NEWS

home. THE STRAITS TIMES SATURDAY, MARCH 26 2011

Invention zooms in on ultra-tiny objects

S'pore scientists in team that modified microscope to view minuscule items

By Lester Kok

LIVE viruses may no longer be able to "hide".

An international research team, whose members include Singapore scientists, has found a way to cheaply modify microscopes to zoom in on ultra-tiny objects.

Microscopes generally allow for objects of up to one micrometre in size to be seen. The invention allows for objects up to 50 nanometres – or one-20th the size – to be viewed. The severe acute respiratory syndrome virus, for example, is 70 nanometres in size.

Unlike current techniques, which can take hours to scan an object of that minuscule size, the new "nanoscope" can be used in real time and under normal light.

The invention came from a collaboration between the Data Storage Institute (DSI), National University of Singapore (NUS) and University of Manchester.

One of the lead researchers, Associate Professor Hong Minghui from NUS' department of electrical and computer engineering, said ordinary glass beads are used in the microscope to magnify objects.

He added that the modification potentially allows scientists to examine live viruses, a job beyond the scope of existing microscopes.

Current technology used to view objects at the nanoscale uses special light sources such as lasers, which may damage the specimens.

"This project was a very tough challenge but it has a high impact for the research industry," said Prof Hong.

His co-researcher is Professor Boris Luk'yanchuk from DSI, one of the research institutes overseen by the Agency for Science, Technology and Research.

The Russian physicist said the challenge was to get crisp, sharp images despite the large magnification.

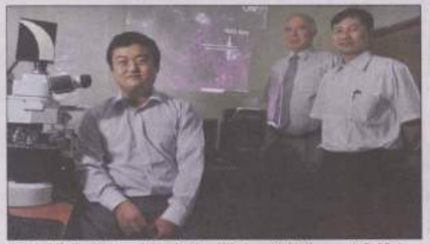
Their research was published this month in Nature Communications, a respected scientific journal.

If successfully commercialised, the "nanoscope" would be a cheap add-on to existing microscopes. Future plans include making the glass beads into arrays that would increase the speed of analysing samples, but more funding is needed, said the scientists.

Prof Hong said this project also proved that Singapore universities produce world-class researchers, as their research counterpart from the University of Manchester, Dr Wang Zengbo, is his former student from NUS.

Dr Wang, from China, was in the DSI's laser research group while doing his doctorate studies here from 2000 to 2005.

lesterk@sph.com.sg


(From left) Mr Chen Zaichun, a PhD student from NUS who assisted in the research, Prof Boris Luk'yanchuk and Prof Hong Minghui helped develop a way to cheaply modify microscopes so minuscule specimens can be viewed in real time and under normal light. ST PHOTO: KURIA LING

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5 Mar 2011 ... *New York Times* .... New *nanoscope* sees objects smaller than ever ... researchers designed a *nanoscope* that allows scientists to image ...

"Microsphere *nanoscope*" makes infinitesimal living viruses visible

ScienceDaily®

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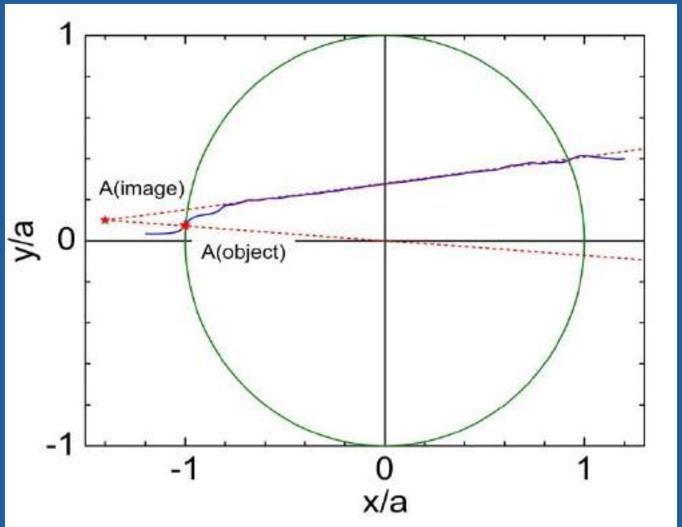
World's Most Powerful Optical Microscope: Microscope Could 'Solve the Cause of Viruses'

ScienceDaily (Mar. 2, 2011) — Scientists have produced the world's most powerful optical microscope, which could help us to understand the causes of many diseases. Writing in the journal *Nature Communications*, the team have created a microscope which shatters the record for the smallest object the eye can see, beating the diffraction limit of light.

Innovation on msnbc.com



Diffraction limit

$$\Delta = \lambda / 2n$$

λ = 600 nm, n = 1.5, Δ = 200 nm

Construction of virtual image according to reciprocity principle

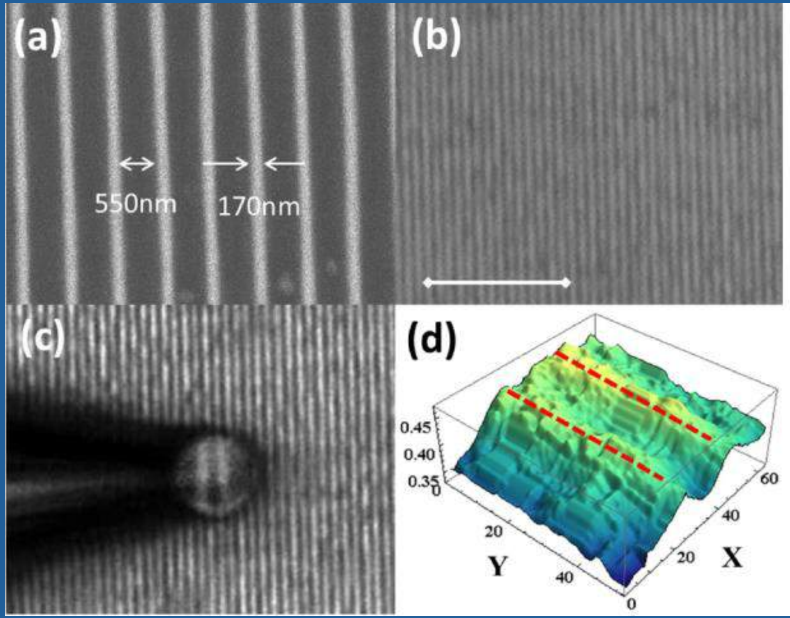
nature COMMUNICATIONS

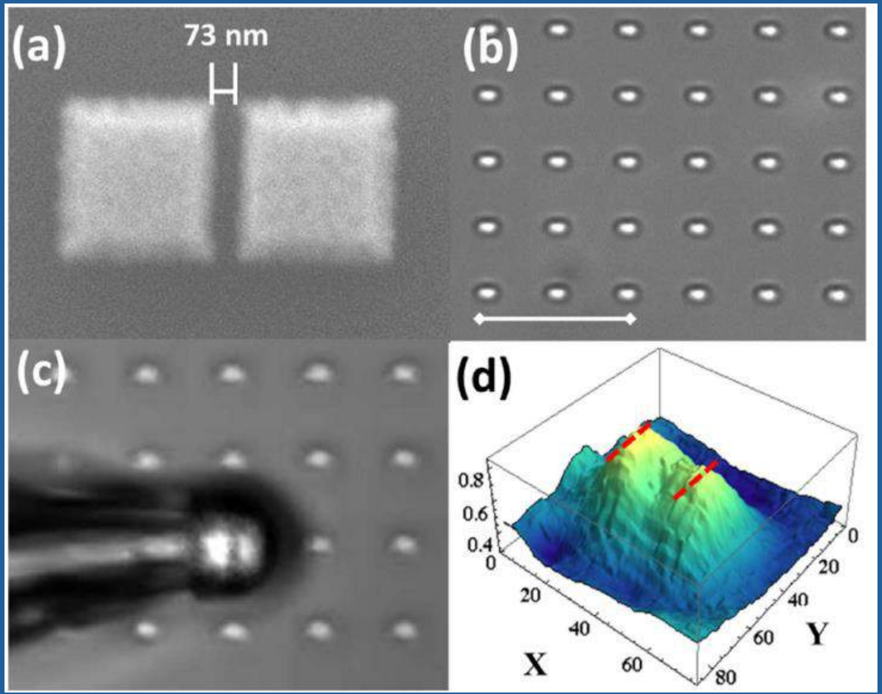
ARTICLE

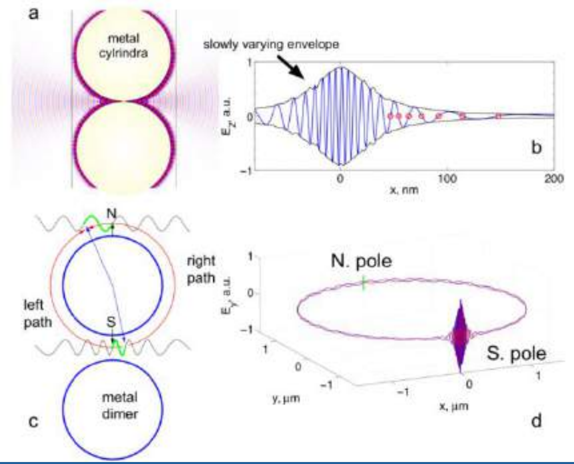
Received 20 Jan 2015 | Accepted 30 Jun 2015 | Published 10 Aug 2015 DOI: 10.1038/ncomms8942

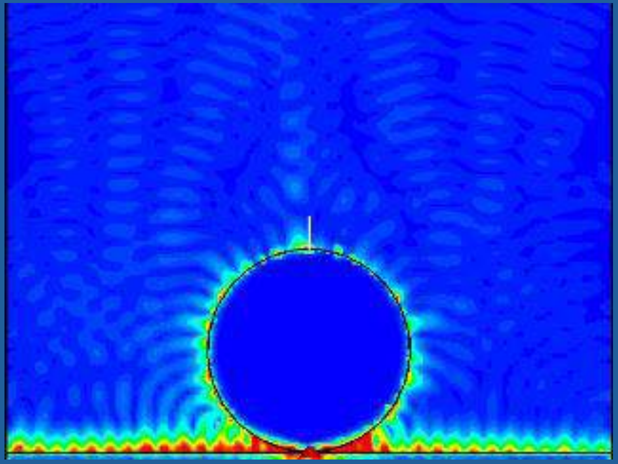
Adiabatic far-field sub-diffraction imaging

Hu Cang[1,2,*], Alessandro Salandrino[1,*], Yuan Wang[1,*] & Xiang Zhang[1,3,4]









SCIENTIFIC REPORTS

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26 September 2013

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Locomotion of microspheres for super-resolution imaging

Leonid A. Krivitsky[1], Jia Jun Wang[1], Zengbo Wang[2] & Boris Luk'yanchuk[1]

[1]Data Storage Institute, Agency for Science Technology and Research, 5 Engineering Drive I, 117608 Singapore, [2]School of Electronic Engineering, Bangor University, Dean Street, Bangor LL57 1UT, Gwynedd, UK.

Super-resolution virtual imaging by micron sized transparent beads (microspheres) was recently demonstrated by Wang *et al.* Practical applications in microscopy require control over the positioning of the microspheres. Here we present a method of positioning and controllable movement of a microsphere by using a fine glass micropipette. This allows sub-diffraction imaging at arbitrary points in three dimensions, as well as the ability to track moving objects. The results are relevant to a broad scope of applications, including sample inspection, microfabrication, and bio-imaging.

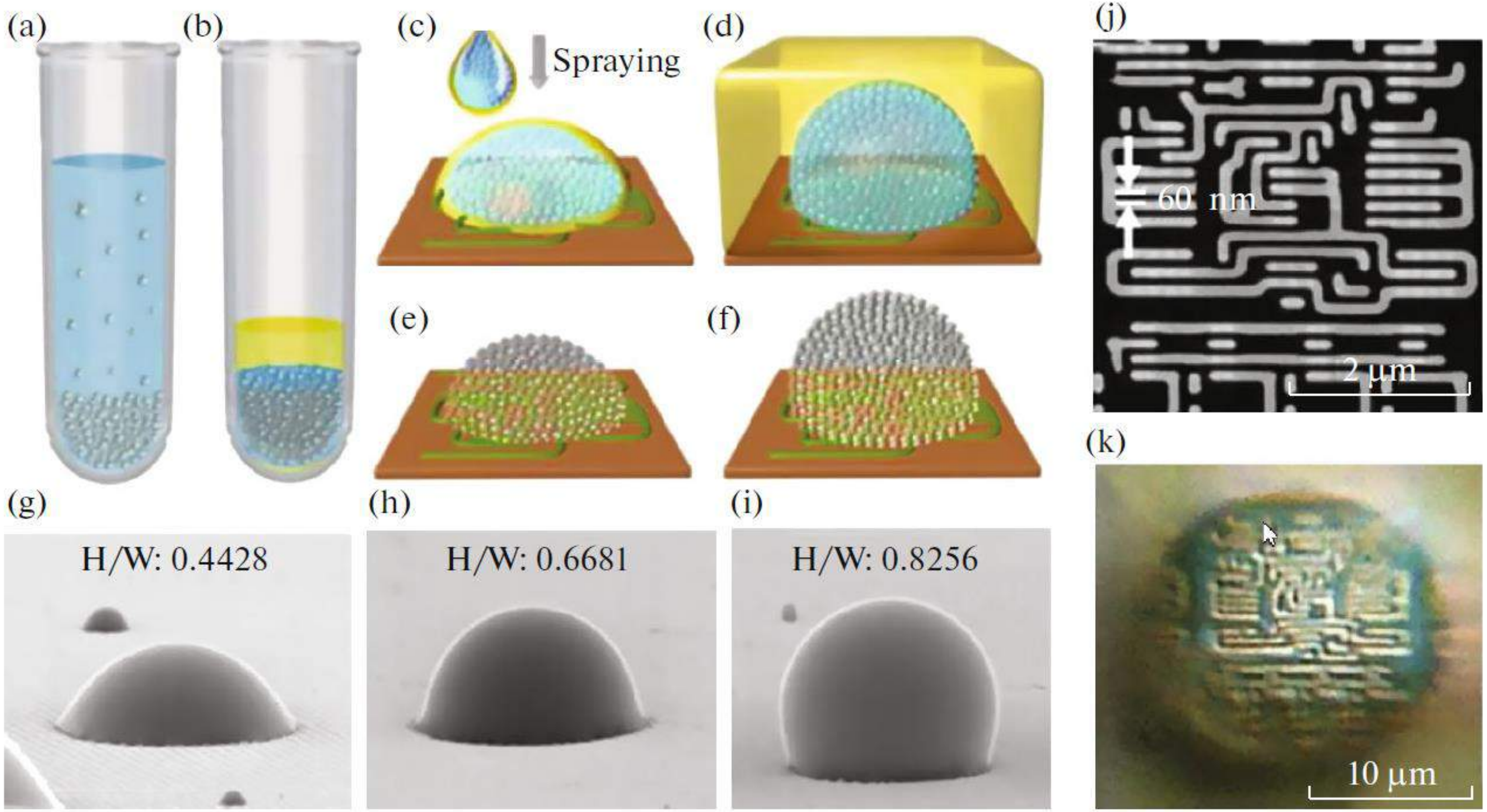
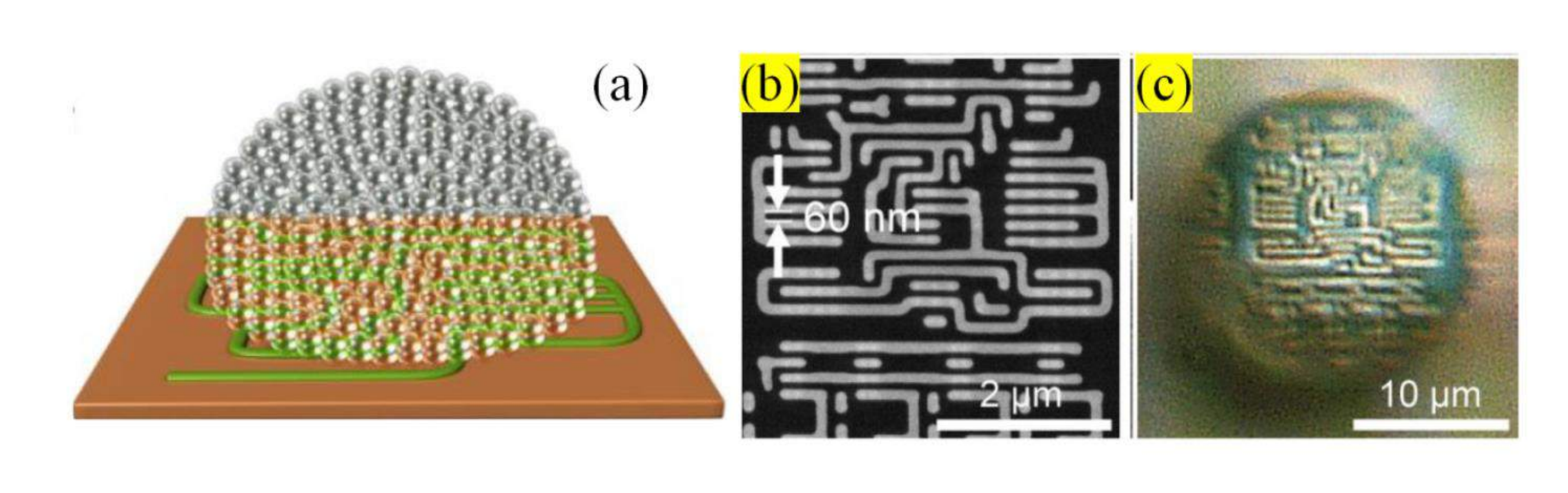
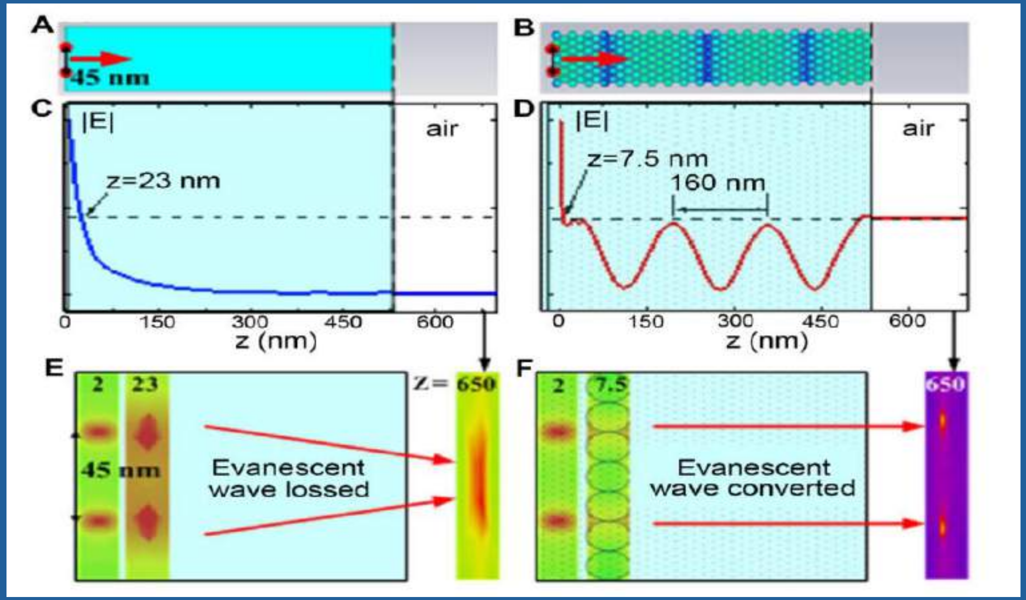


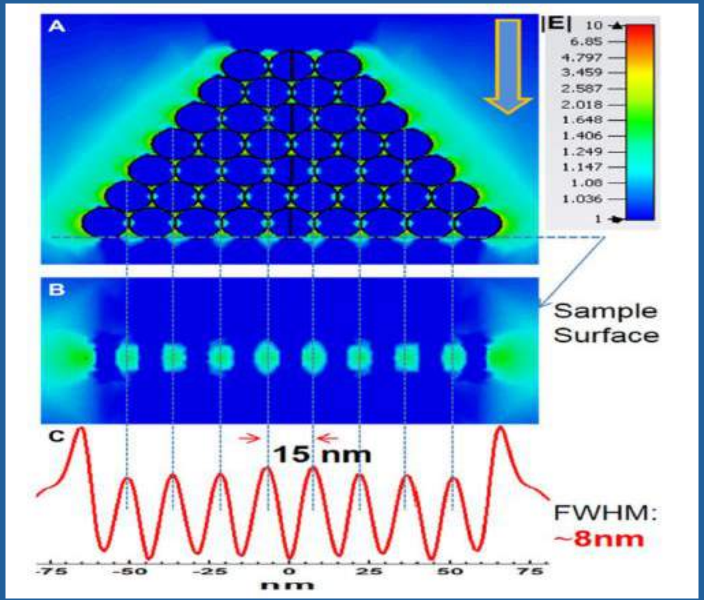
Fig. 6. (Color online) Schematics of the formation of a lens from a metamaterial, collected by cluster assembly. (a) Anatase nanoparticles (15-nm TiO_2) are centrifuged to form a dense precipitate; (b) the liquid above the precipitate is replaced with a mixture of organic solvents (hexane and tetrachloroethylene), which form a "nanofluid fraction" (NFF) of TiO_2; (c) to from a hemispherical metamaterial, this NFF is deposited as a "drop" directly on the sample surface; (d) to from a hemispherical metamaterial, this drop is coated by a thin layer of a mixture of organic solvents; (e, f) after the solvent evaporation the "drop" undergoes a phase transition with the formation of a more closely packed metamaterial; (g–i) fabricated lenses with different height-to-diameter ratios; (j) SEM image of a part of an integrated circuit with 60-nm elements; and (k) a view of the same integrated circuit in an optical microscope with a 15-μm metamaterial lens [32].

Optical nanoscopy with cluster assembled materials, e.g. 15 nm TiO2 nanoparticles



W. Fan, B. Yan, Z. Wang, L. Wu. *Three-dimensional all-dielectric metamaterial solid immersion lens for subwavelength imaging at visible frequencies*. Science Advances **2**, e1600901 (2016)





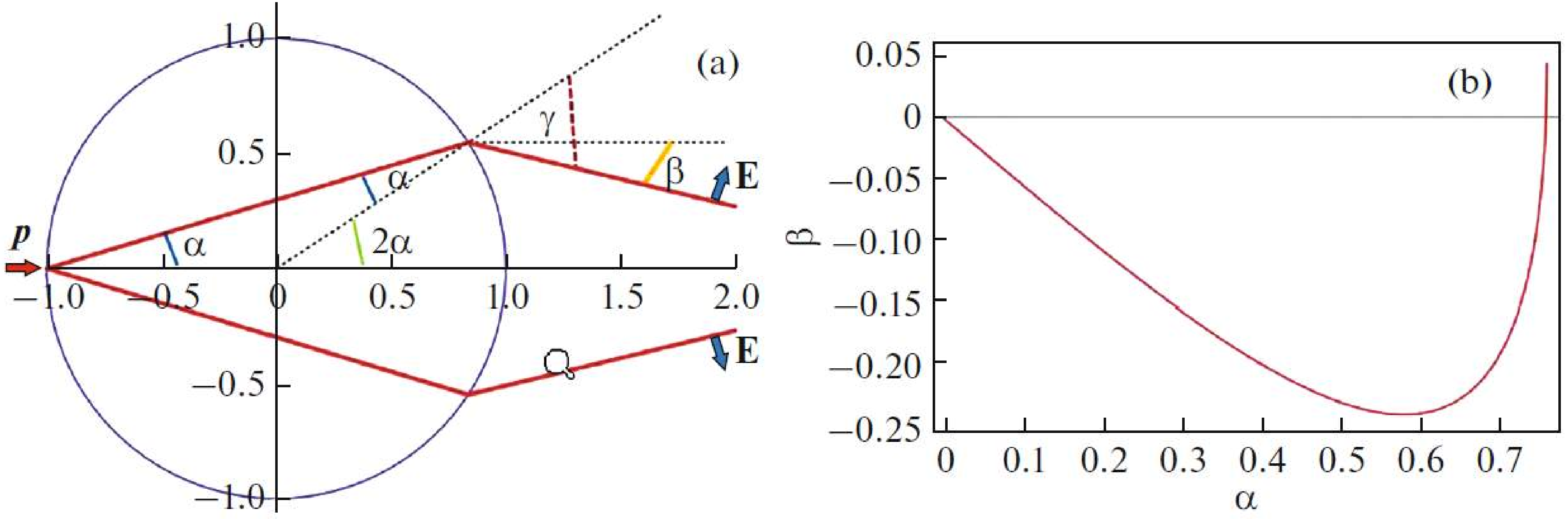
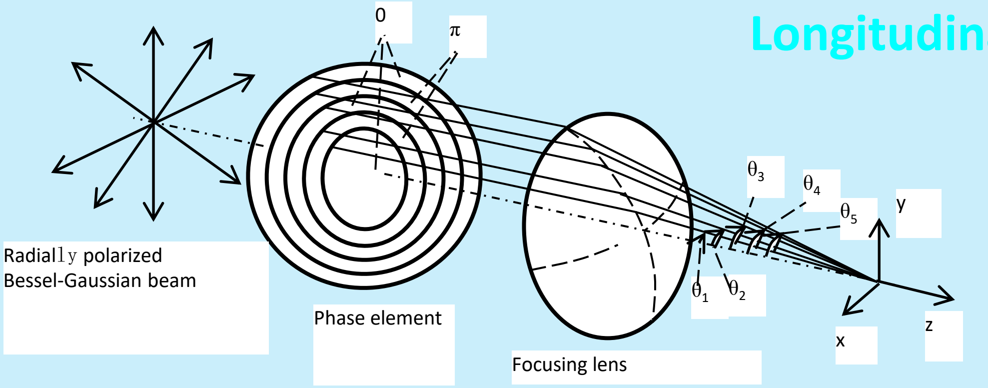
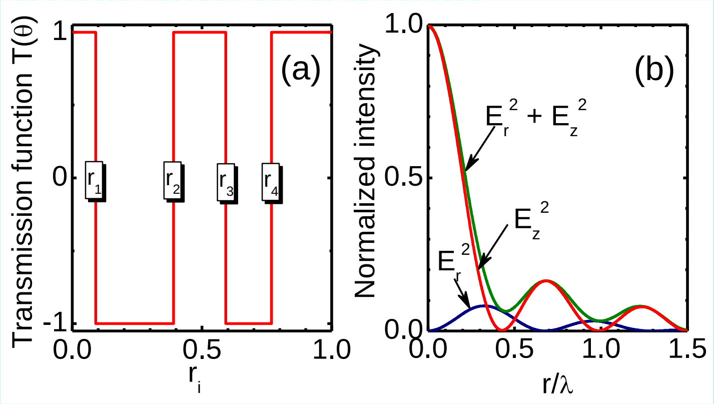


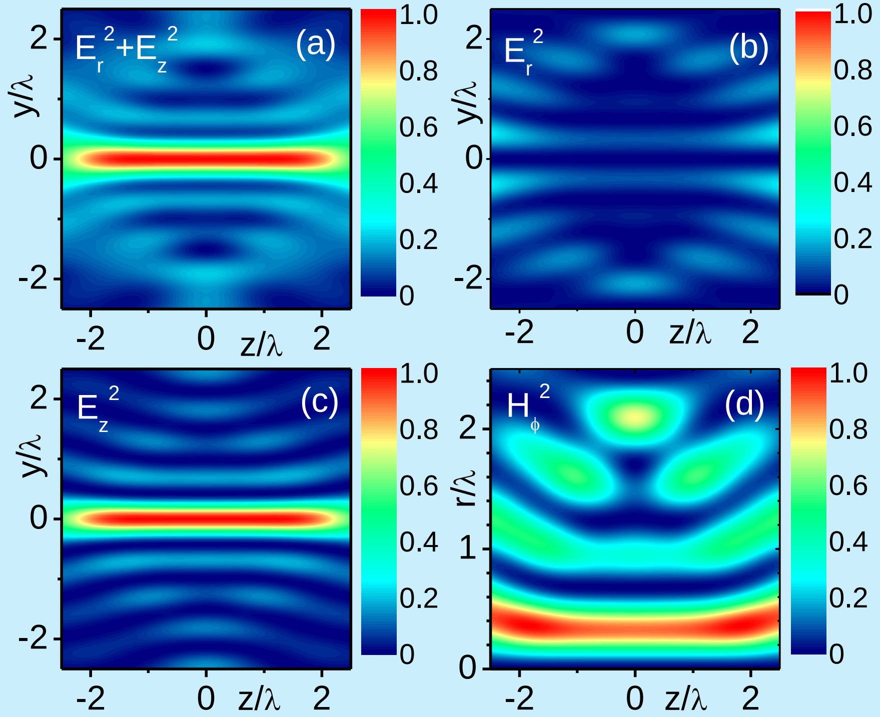
Fig. 7. (Color online) (a) The point light source is a radially polarized dipole ***p***, located near the surface of a sphere. A ray from this source propagates at an angle α, smaller than the total internal reflection angle. At the output of the sphere this ray is refracted at an angle $\gamma = \arcsin(n \sin\alpha)$ and propagates at an angle β with respect to the axis [9]. (b) Example of a solution to Eq. (4) at $n = 1.45$.

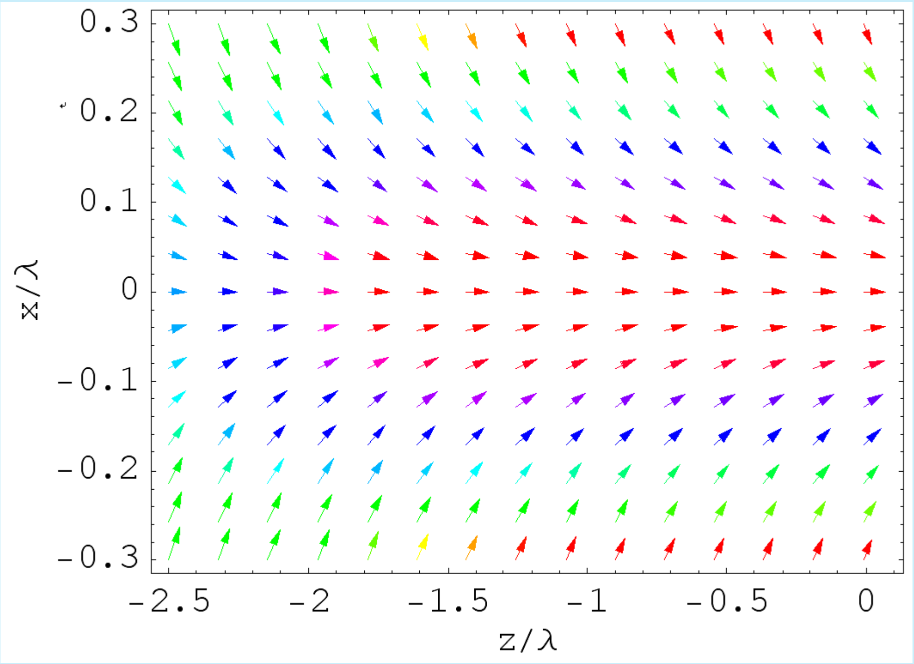
C. Simovsky and R. Heydarian, "A simple glass microsphere may put the end to the metamaterial superlens story," *AIP Conf. Proc.* **2300**, 020117 (2020).

Longitudinally polarized light in vacuum









Wang H. F., L. Shi L.P., Luk'yanchuk B. S., Sheppard C. J. R., Chong T.C.

Creation of a needle of longitudinal polarized light in vacuum using binary optics

Nature Photonics, **2**, pp. 501-505 **(2008)**

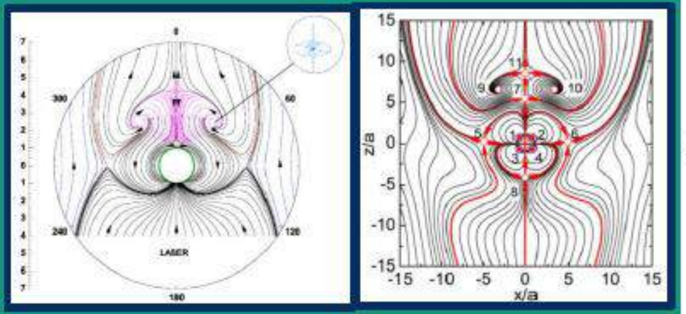
Descartes 1596-1650

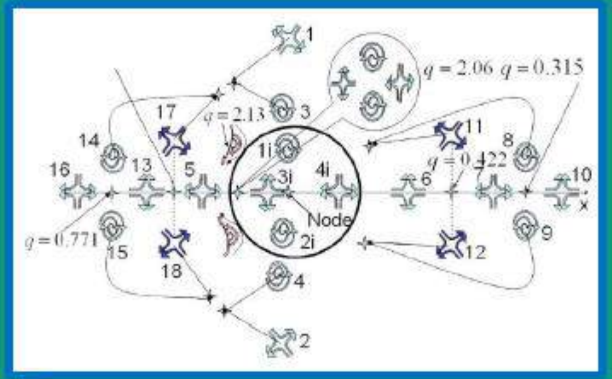
In 1644 René Descartes' suggested the universal role of vortices in Nature.

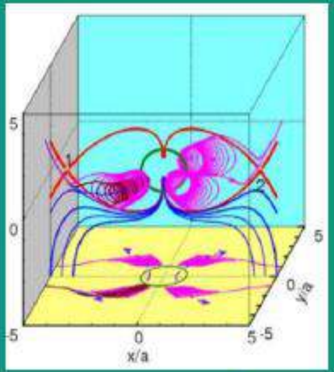
Optical nanovortices generated by spherical particle or cylinders

Z. B. Wang et al, *Phys. Rev. B* **70**, 035418 (2004)

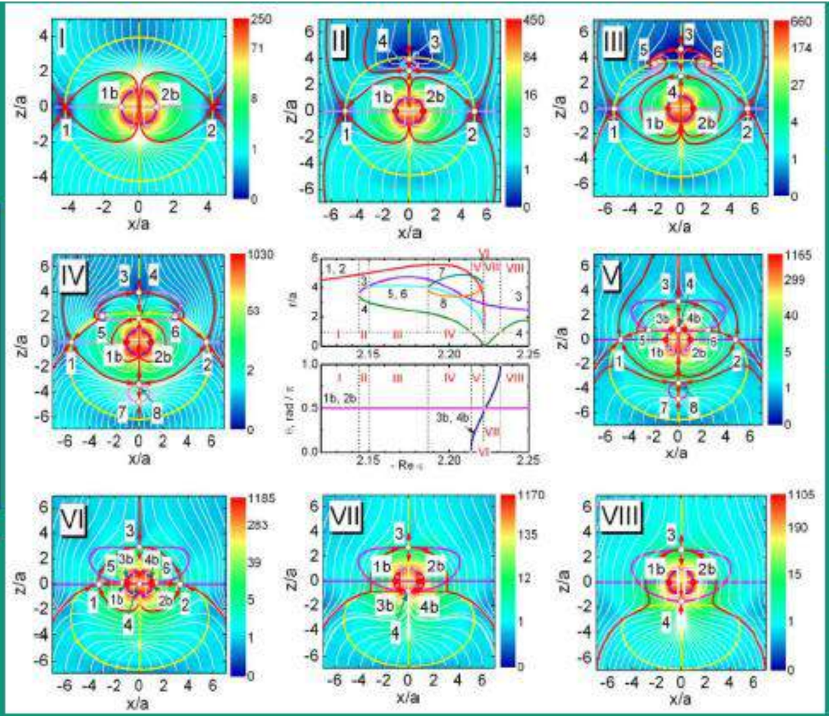
B. Luk`yanchuk et al, *J. Opt.* **15**, 073001 (2013)

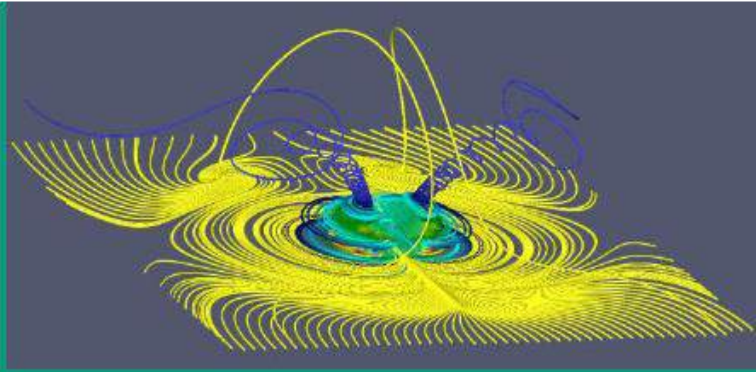


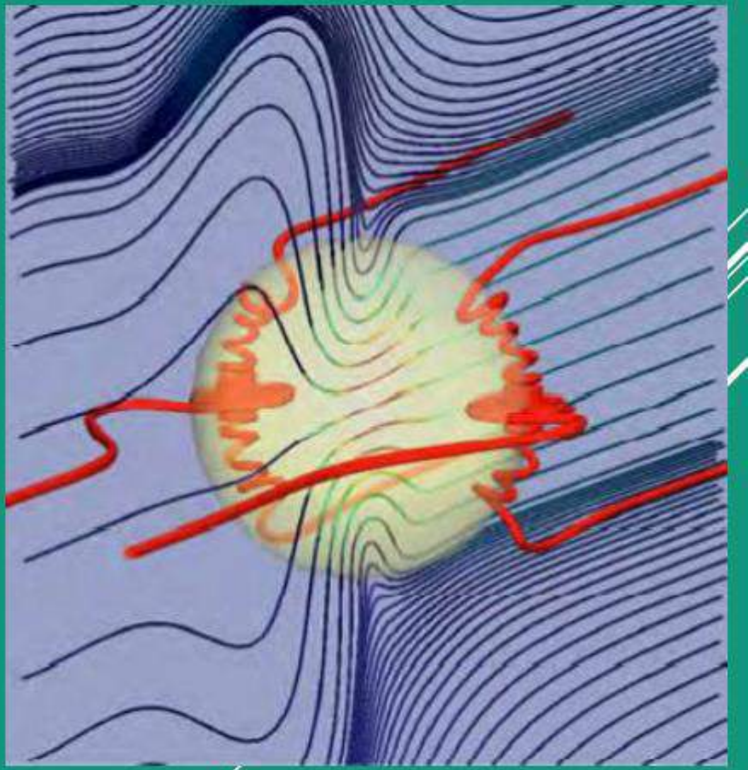


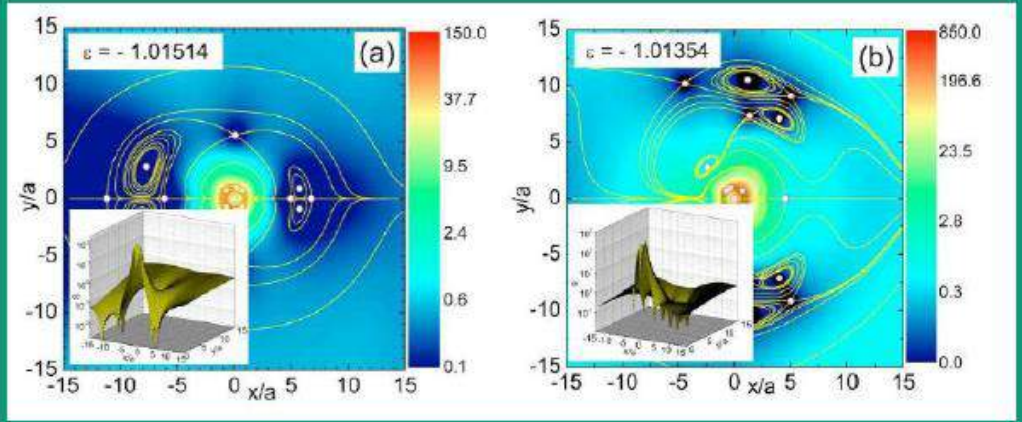


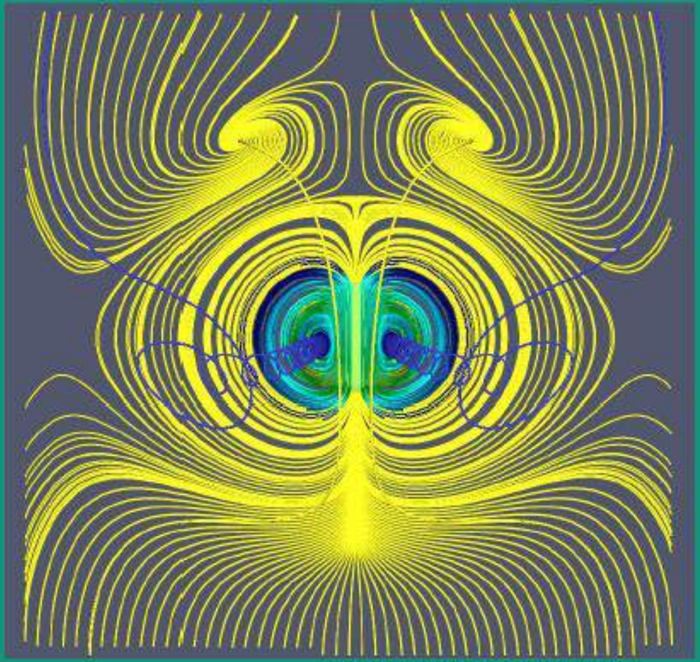
B. Luk'yanchuk et al., *Phys. Rev. B* **73**, 235432 (2006)











Poynting vector energy flow for a dielectric particle at the magnetic resonance for a size parameter q = 1 and ε = 9.1. Red lines show characteristic separatrices.

B. Luk'yanchuk et al, J. Opt. 15, 073001 (2013)

Opto-Electronic Science

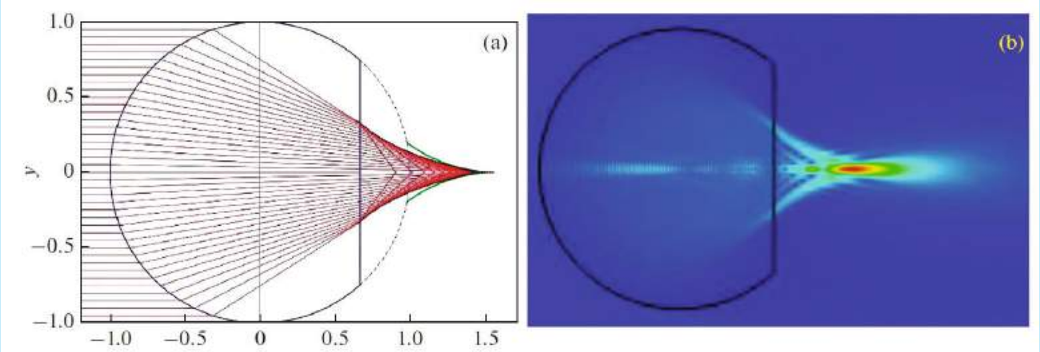
Orignal Article

2022, Vol. 1, No. 2

DOI: 10.29026/oes.2022.210008

Photonic lenses with whispering gallery waves at Janus particles

Igor V. Minin[1], Oleg V. Minin[1], Yinghui Cao[2], Bing Yan[3], Zengbo Wang[3] and Boris Luk'yanchuk[4*]



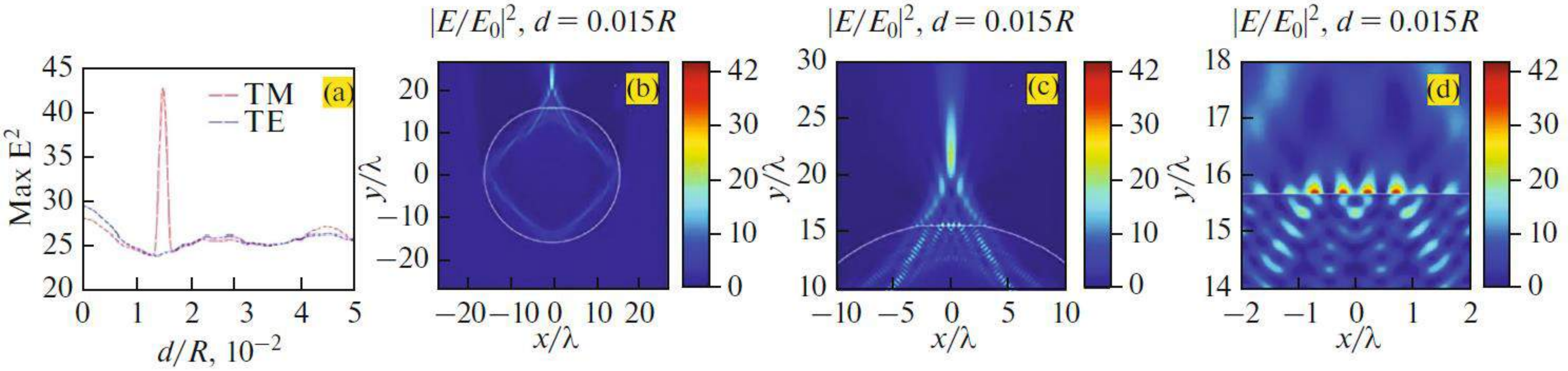


Fig. 14. (Color online) (a) Resonant effect for field amplification in a truncated cylinder, depending on the truncated-element thickness; refractive index $n = 1.5$, $q = 2\pi R/\lambda = 100$. The resonance is observed for only the TM mode and is not observed for the TE mode. (b–d) Intensity distributions at the resonant truncation value $h = d/R = 0.015$ for different magnifications [61].

Opto-Electronic Science

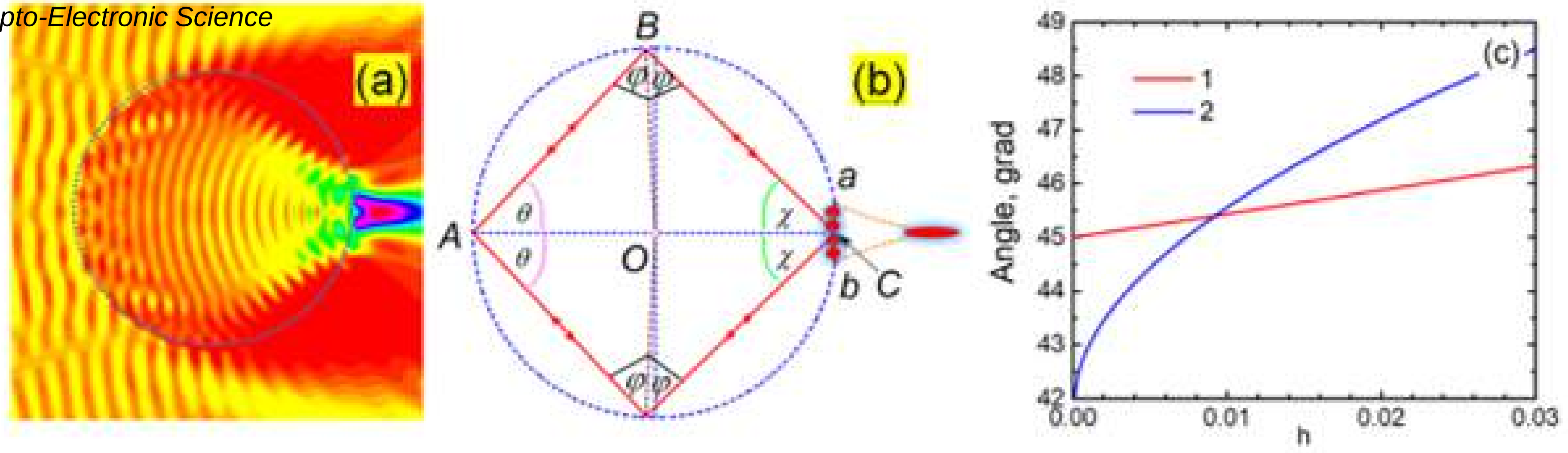
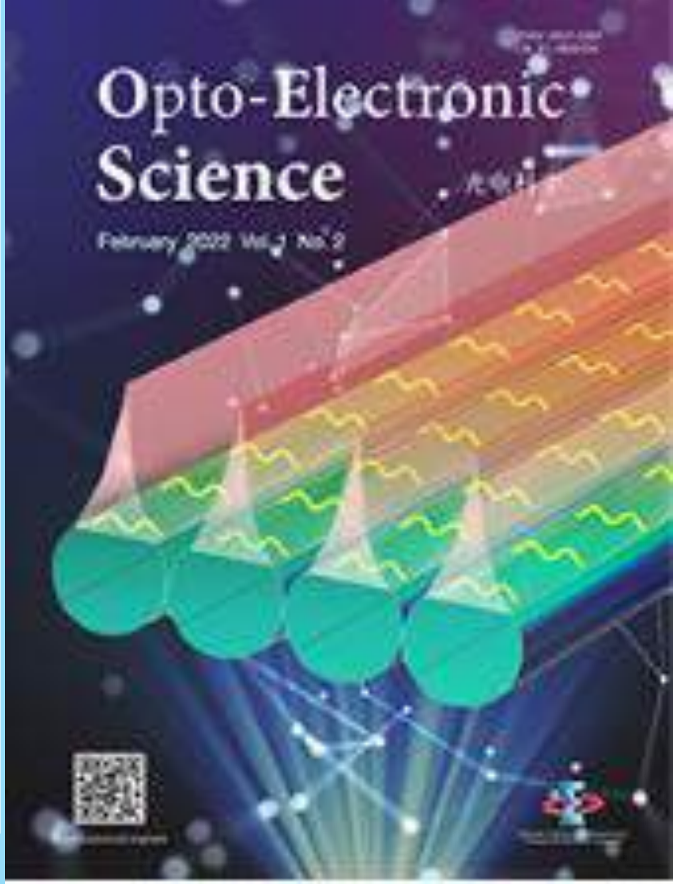


Рис. 15. Распределение интенсивности $I = |\mathbf{E}|^2$ в сечении цилиндра с показателем преломления $n = 1.5$ и параметром размера $q = 10$, согласно формулам (8)-(15) (a). Ход лучей в частице Януса в случае падения луча на плоскую поверхность под углом полного внутреннего отражения χ (b). Резонансный угол χ (кривая 1) и угол полного внутреннего отражения (кривая 2) (c).



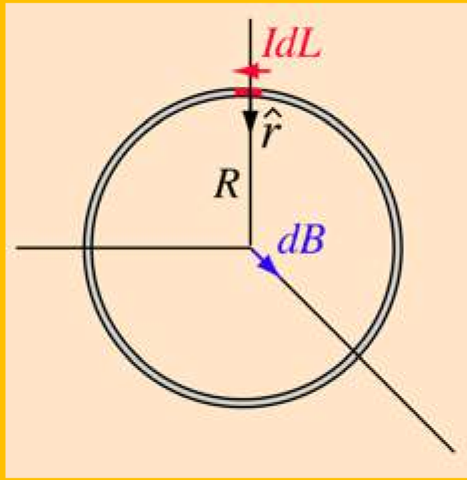
Photonic lenses with whispering gallery waves at Janus particles

Igor V. Minin, Oleg V. Minin, Yinghui Cao, Bing Yan, Zengbo Wang, Boris Luk'yanchuk

Opto-Electronic Science **1**, no. 2, 210008 (2022)

Why we have so big magnetic fields?

From the Biot-Savart law follows the field at center of current loop



$$B = \frac{\mu_0 I}{4\pi R^2}\oint dL = \frac{\mu_0 I}{4\pi R^2} 2\pi R = \frac{\mu_0 I}{2R}$$

$$\mu_0 = 4\pi \;\; x \;\; 10^{-7}\, T \cdot m / A$$

For a current *I* = 1 A and the loop with radius 10 nm one can create magnetic induction B = 63.8 Tesla.

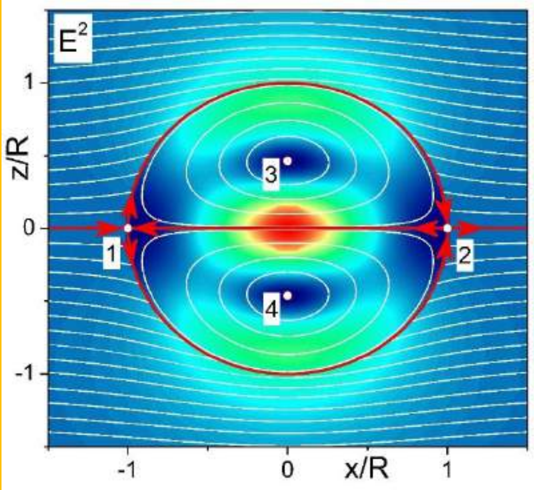
Displacement currents inside the dielectric particle are proportional to laser intensity.

How small can be optical vortices?

For dipole resonance $R \approx \dfrac{\lambda}{4n} \quad \Rightarrow \quad \approx 100\ nm$

For higher order resonances it can be much smaller due to superoscillations effect

M. Berry, N. Zheludev, Y. Aharonov et al.
Roadmap on superoscillations, J. Opt. **21** (2019)
A band-limited function can vary arbitrarily faster than its fastest Fourier component, over arbitrarily long intervals.



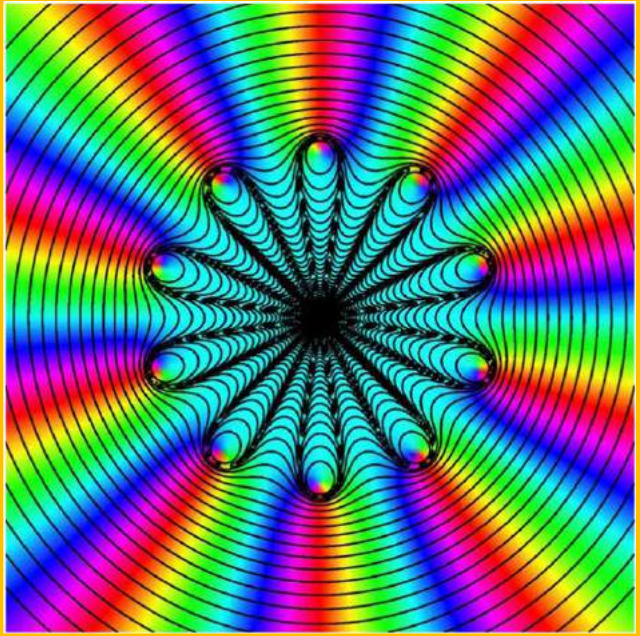


Figure 1. Superoscillatory fine detail in one square wavelength of the monochromatic wave $\psi = J_m(r)\exp(im\phi) + \varepsilon J_0(r)$ for $m = 1$, $\varepsilon = 10^{-7}$ over one square wavelength. The phase $\arg\psi$ is colour-coded, and the optical vortices are the ten points where all colours meet; superimposed are the lines of local wavevector grad($\arg\psi$).

Uncertainty principle

$$\Delta E \cdot \Delta t \geq \hbar \quad \Rightarrow \quad \Delta N \cdot \Delta\Phi \geq 1, \quad k_{local} = \nabla\Phi$$

Conclusions

Optical Phenomena in Dielectric Spheres Several Light Wavelengths in Size: A Review

B. S. Luk'yanchuk, A. R. Bekirov, Z. B. Wang, I. V. Minin, O. V. Minin, and A. A. Fedyanin

Physics of Wave Phenomena, 2022, Vol. 30, No. 4, pp. 217–241.

Optical Phenomena in Mesoscale Dielectric Spheres and Immersion Lenses Based on Janus Particles: A Review

B. S. Luk'yanchuk, A. R. Bekirov, Z. B. Wang, I. V. Minin, O. V. Minin, and A. A. Fedyanin

Physics of Wave Phenomena, 2022, Vol. 30, No. 5, pp. 283–297.

Roadmap on Label-Free Super-Resolution Imaging

Vasily N. Astratov, Yair Ben Sahel, Yonina C. Eldar, Luzhe Huang, Aydogan Ozcan, Nikolay Zheludev, Junxiang Zhao, Zachary Burns, Zhaowei Liu, Evgenii Narimanov, Neha Goswami, Gabriel Popescu, Emanuel Pfitzner, Philipp Kukura, Yi-Teng Hsiao, Chia-Lung Hsieh, Brian Abbey, Alberto Diaspro, Aymeric LeGratiet, Paolo Bianchini, Natan T. Shaked, Bertrand Simon, Nicolas Verrier, Matthieu Debailleul, Olivier Haeberlé, Sheng Wang, Mengkun Liu, Yeran Bai, Ji-Xin Cheng, Behjat S. Kariman, Katsumasa Fujita, Moshe Sinvani, Zeev Zalevsky, Xiangping Li, Guan-Jie Huang, Shi-Wei Chu, Omer Tzang, Dror Hershkovitz, Ori Cheshnovsky, Mikko J. Huttunen, Stefan G. Stanciu, Vera N. Smolyaninova, Igor I. Smolyaninov, Ulf Leonhardt, Sahar Sahebdivan, Zengbo Wang, Boris Luk'yanchuk, Limin Wu, Alexey V. Maslov, Boya Jin, Constantin R. Simovski, Stephane Perrin, Paul Montgomery, and Sylvain Lecler*