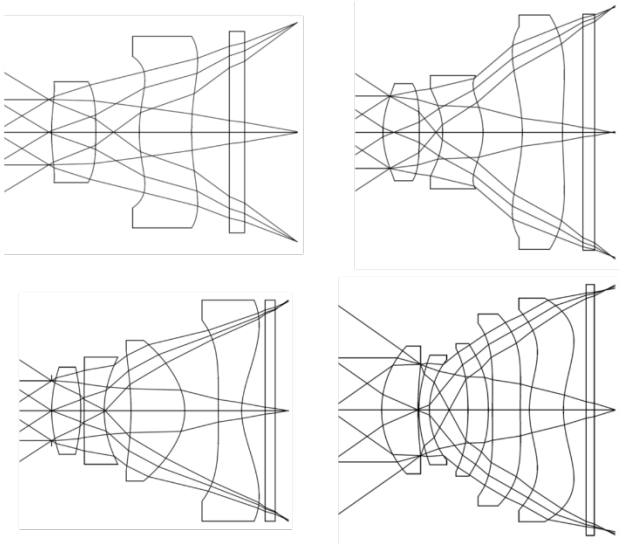
Mobile phone lenses



Lens Design OPTI 696A

Prof. Jose Sasian

College of Optical Sciences
The University of Arizona

Specifications

Typical mobile phone lens specifications			
Year	2006	2012	2018
Focal length	3 mm - 6 mm	3 mm -5 mm	3 mm -5 mm
FOV	66º	72º	78º
F/#	2.8	2.2-2.4	2.0-1.4
TTL	<5.0 mm	<5.0 mm	<6.0 mm
Distortion	<1%-2%	<1%-2%	<1%-2%
CRA	<24º	<30º	<33º
RI	>50%	>50%	>32%
# lens elements	3-5	4-6	5-8

Chief ray angle

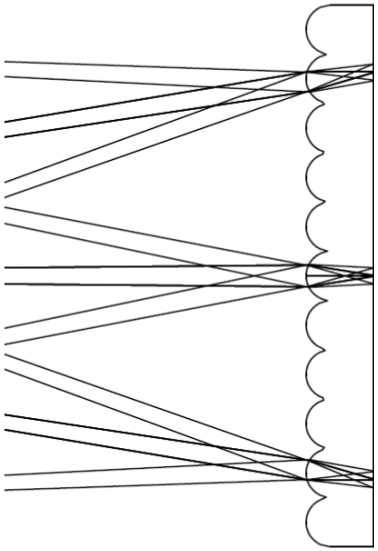
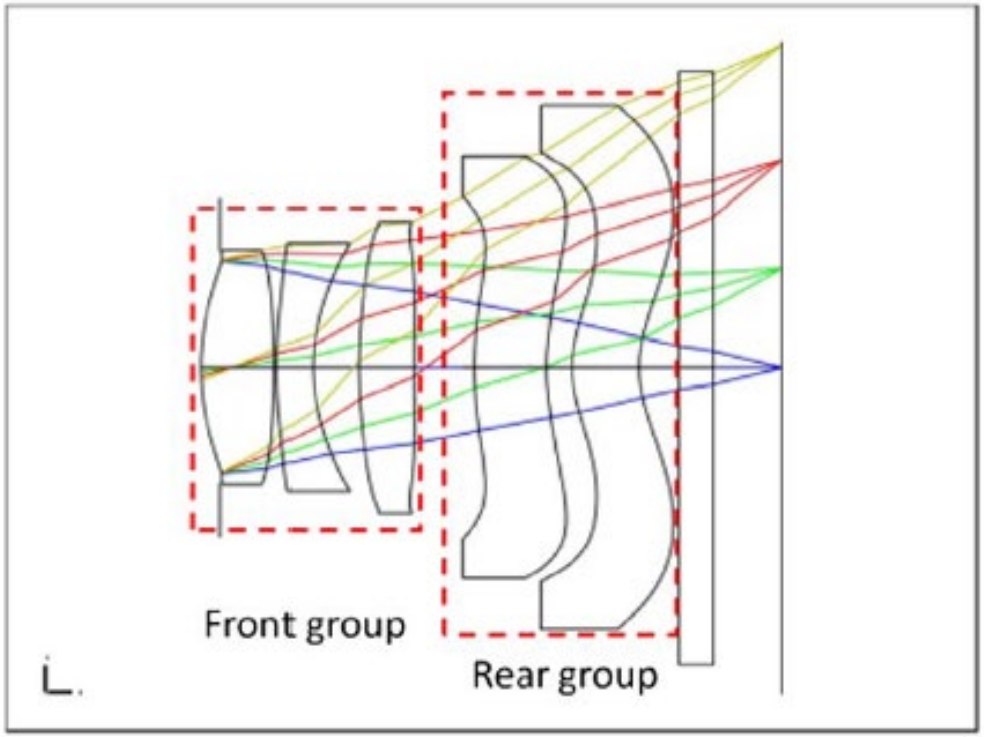


Image quality

Example of MTF specifications in fractions of the Nyquist frequency and in cycles/mm for an object at infinity			
	N_Q	N_Q /2	N_Q /4
MTF On-axis	>40%	>60%	>80%
MTF Off-axis @ 0.7 field	S>30% T>20%	S>50% T>40%	S>70% T>60%
MTF Off-axis @ 1.0 field	S>20% T>10%	S>30% T>20%	S>40% T>30%

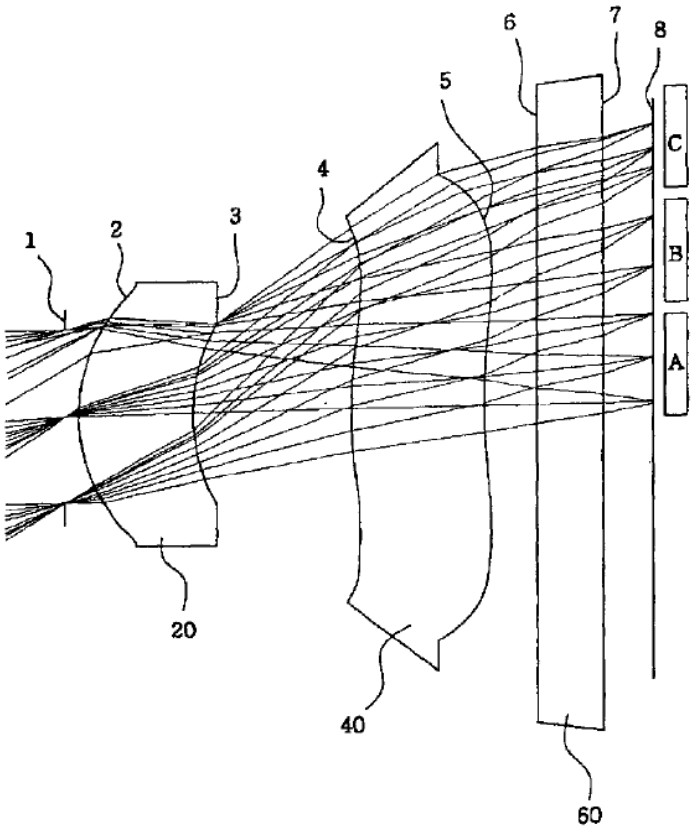
Nq=1/2Xpixelsize
Fc=1/λf#

Aberration correction

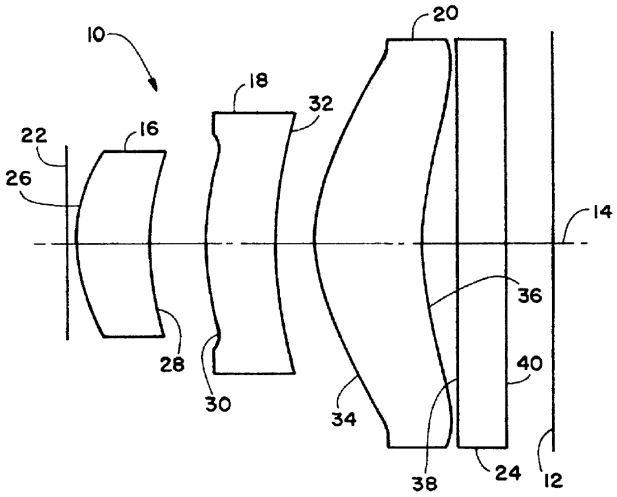


Jo

Patent No.: US 6,853,504 B2
Date of Patent: Feb. 8, 2005



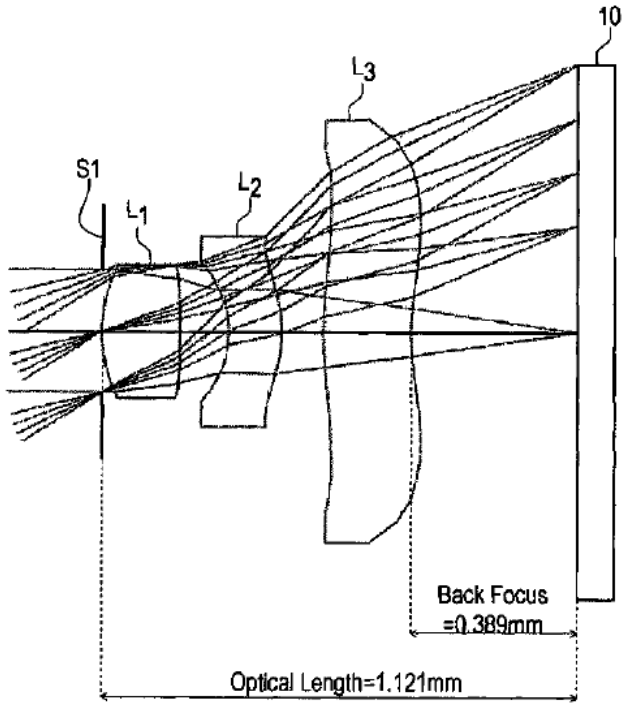
Ning



US 6,441,971 B2
Aug. 27, 2002

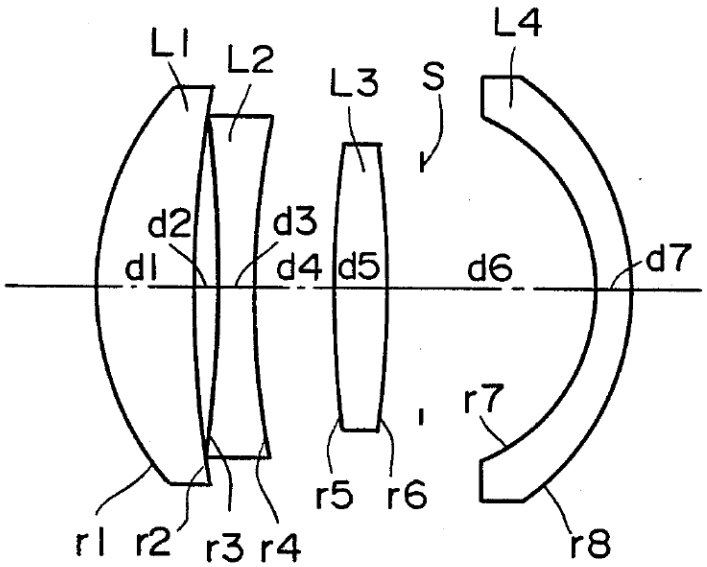
Do

Patent No.: **US 7,675,692 B2**
Date of Patent: **Mar. 9, 2010**



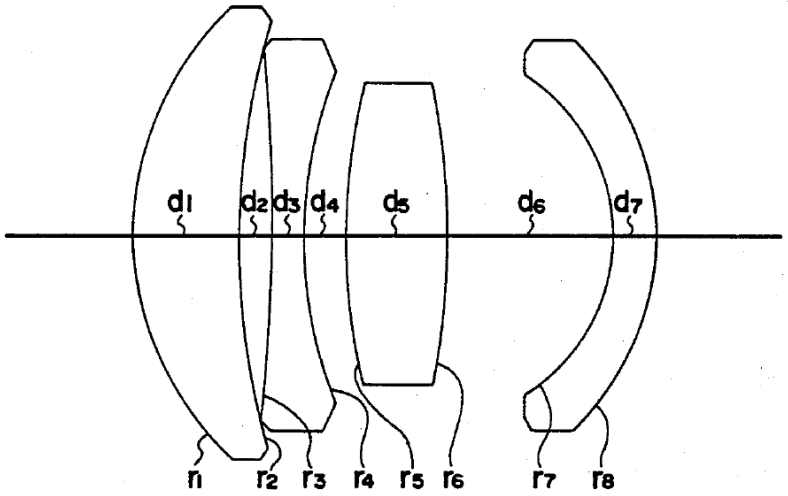
Kudo

Patent Number: **4,792,216**
Date of Patent: **Dec. 20, 1988**



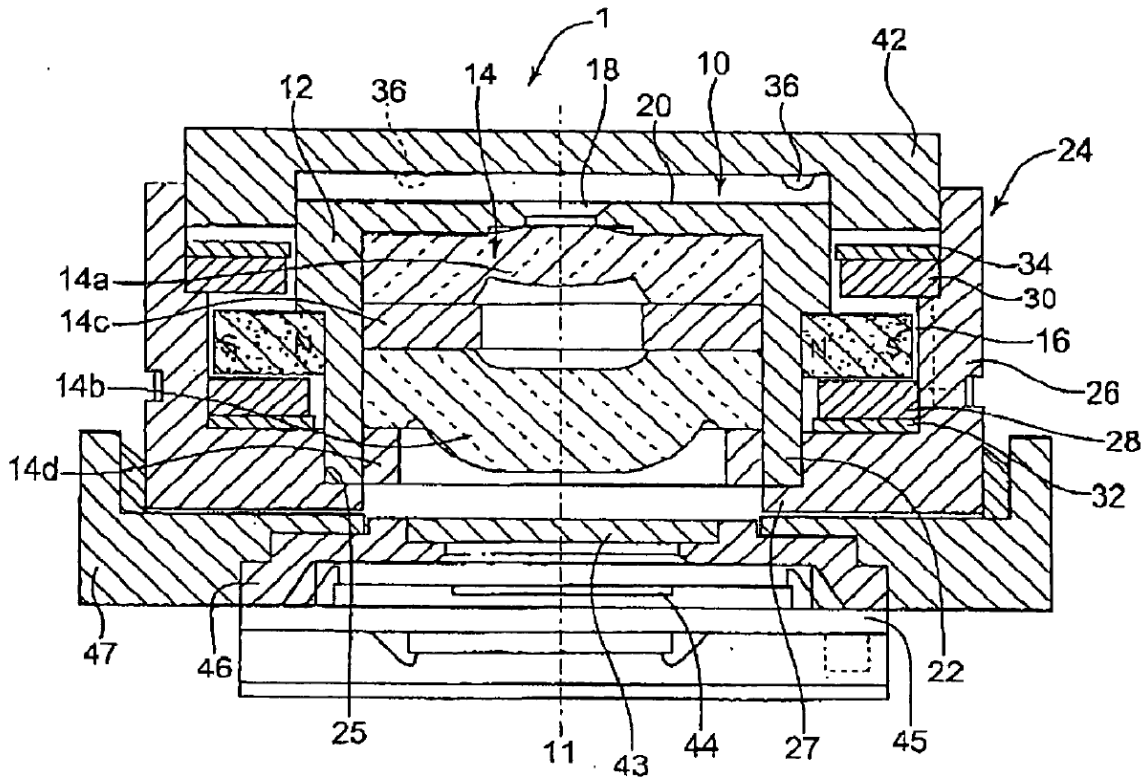
Mihara

Patent Number: **4,659,190**
Date of Patent: **Apr. 21, 1987**



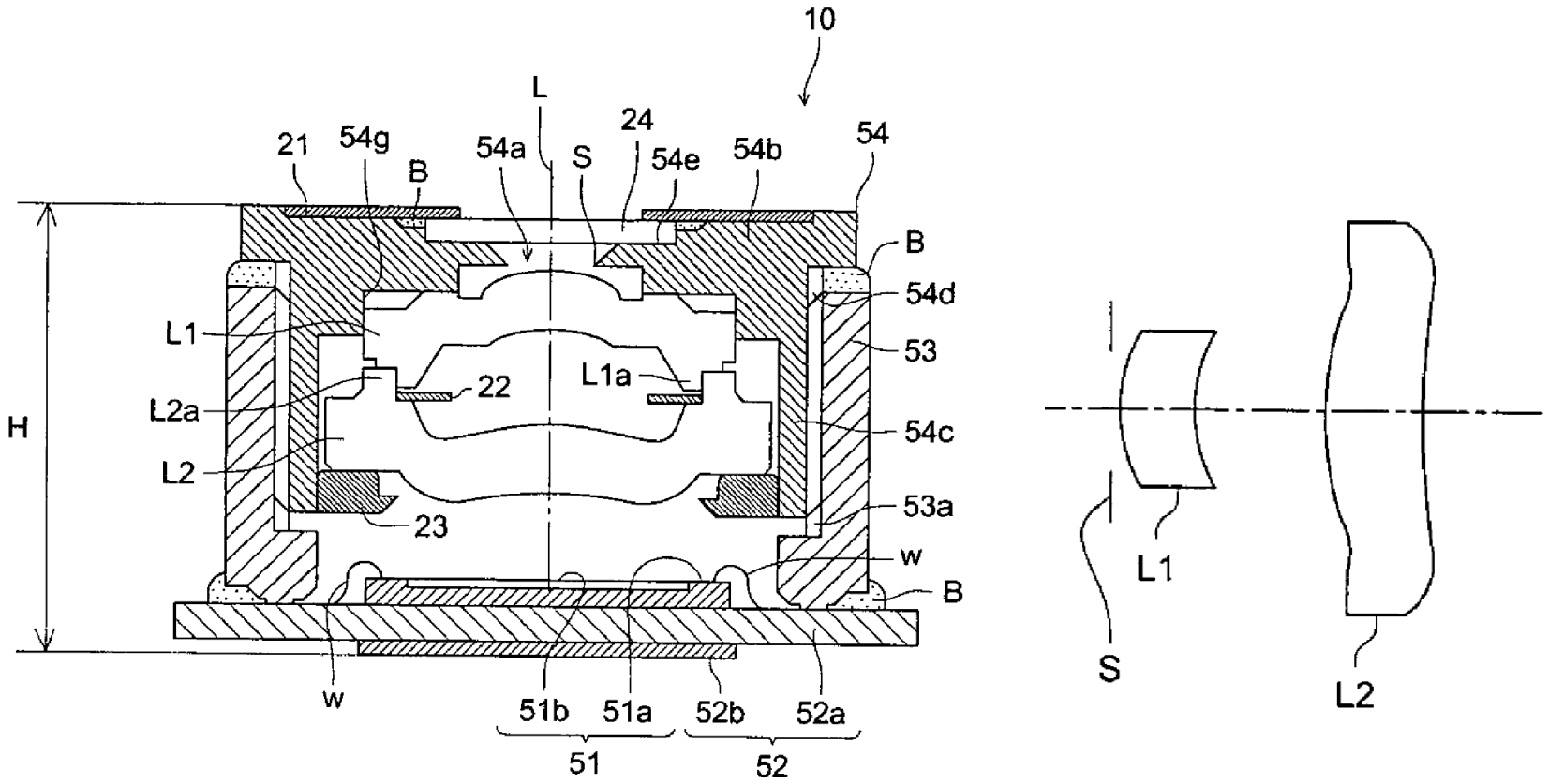
Tsuruta

Pub. No.: US 2004/0207745 A1
Pub. Date: Oct. 21, 2004



Yamaguchi

US 2004/0105173



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Recco

Pub. No.: US 2006/0171046 A1
Pub. Date: Aug. 3, 2006

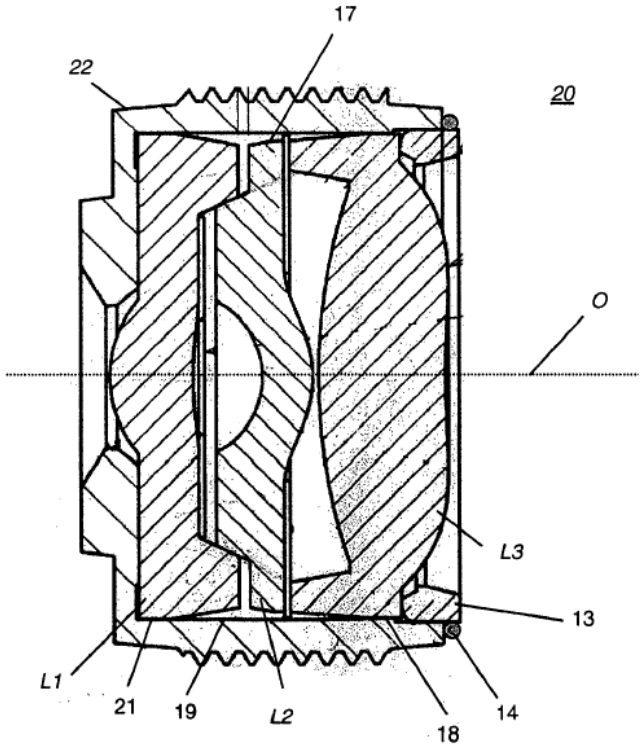
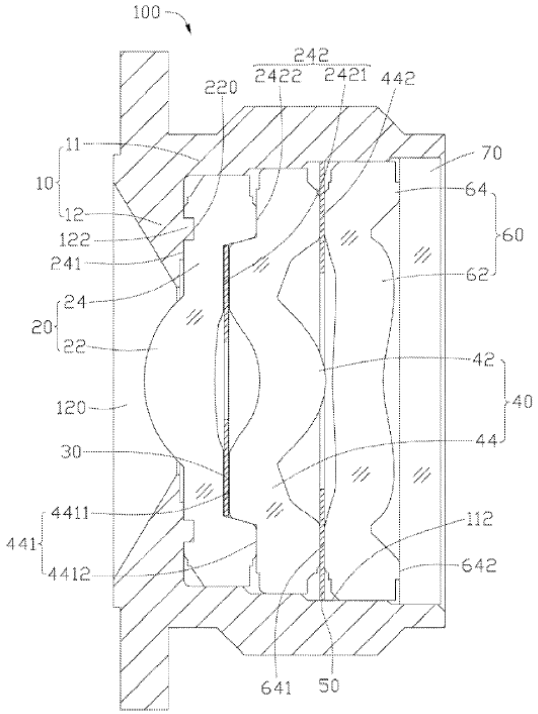


FIG. 2

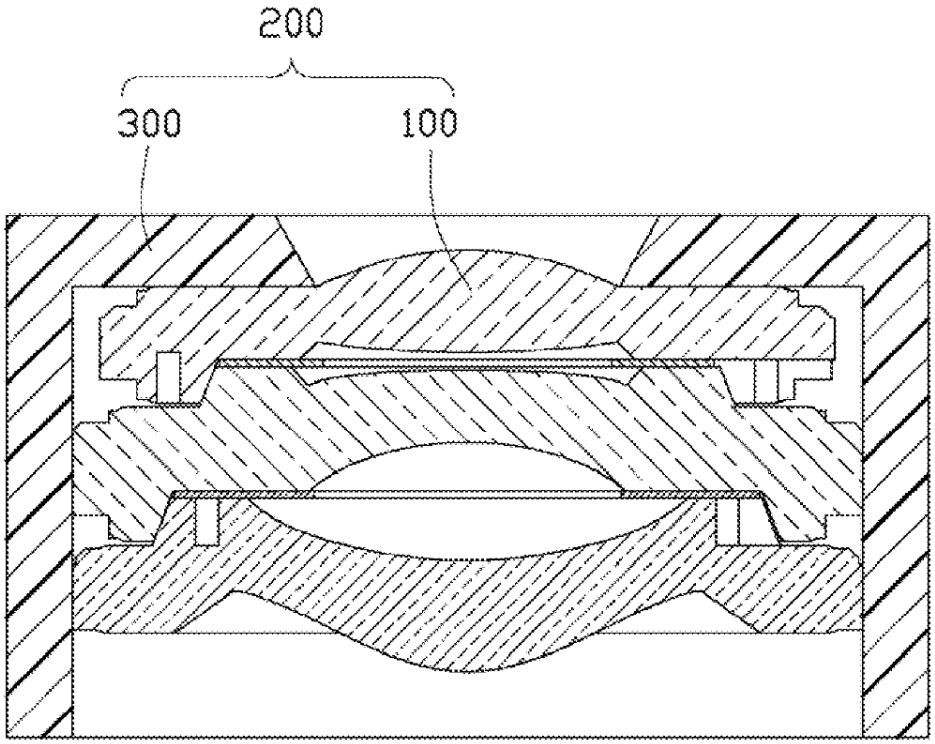
Lin

Pub. No.: US 2013/0050850 A1
Pub. Date: Feb. 28, 2013



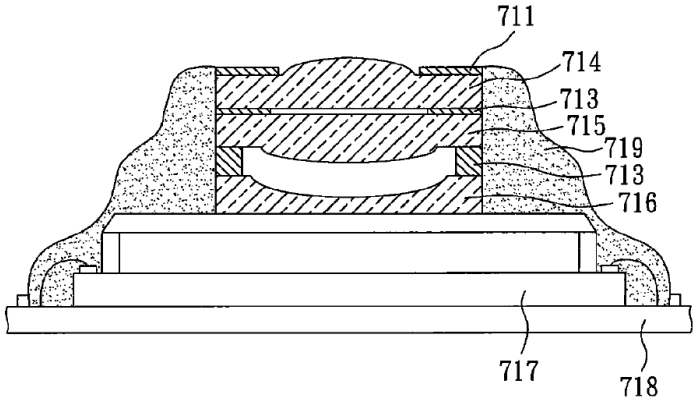
Chou

Pub. No.: US 2011/0090582 A1
Pub. Date: Apr. 21, 2011



Shyu

Patent No.: **US 8,023,208 B2**
Date of Patent: **Sep. 20, 2011**



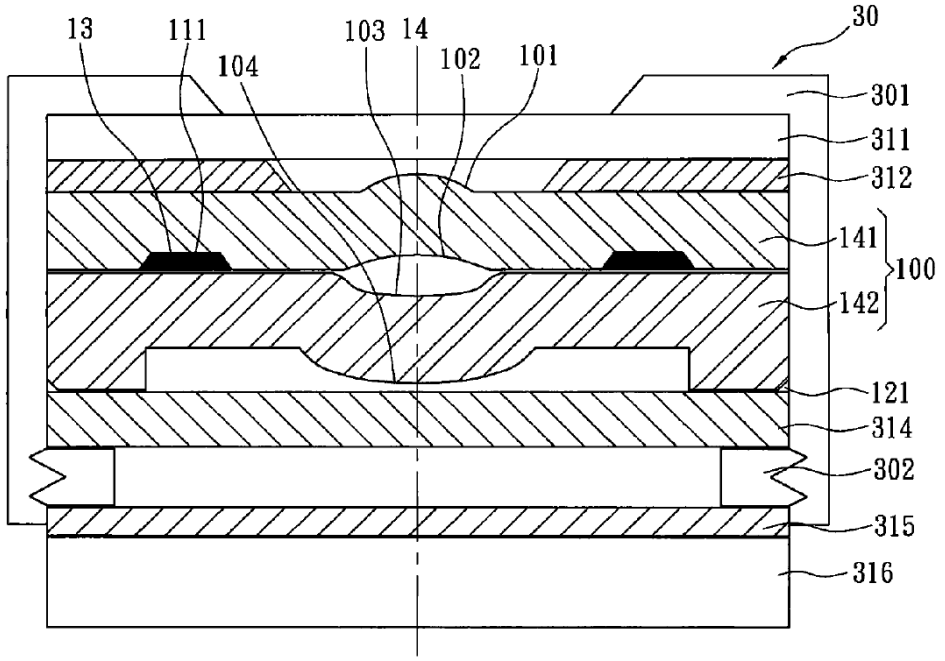


FIG. 3

Lyu

Pub. No.: US 2014/0254034 A1
Pub. Date: Sep. 11, 2014

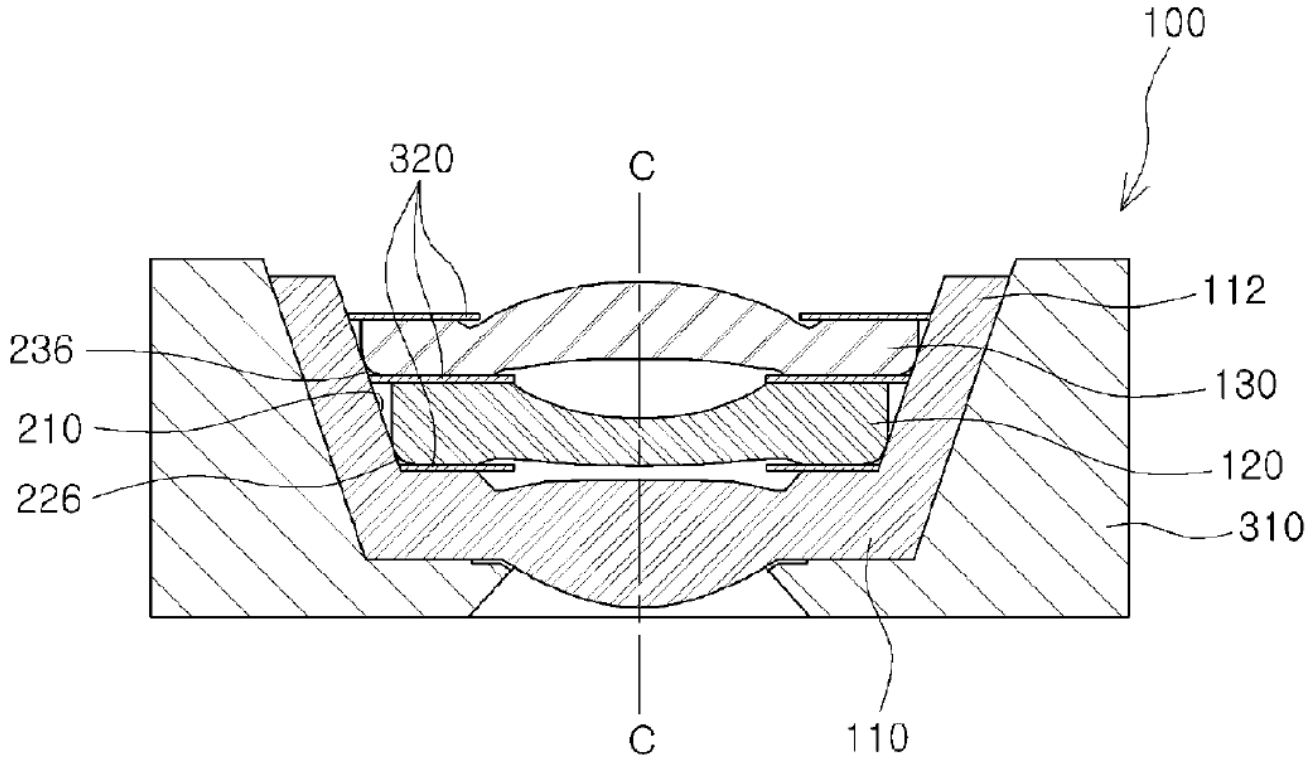
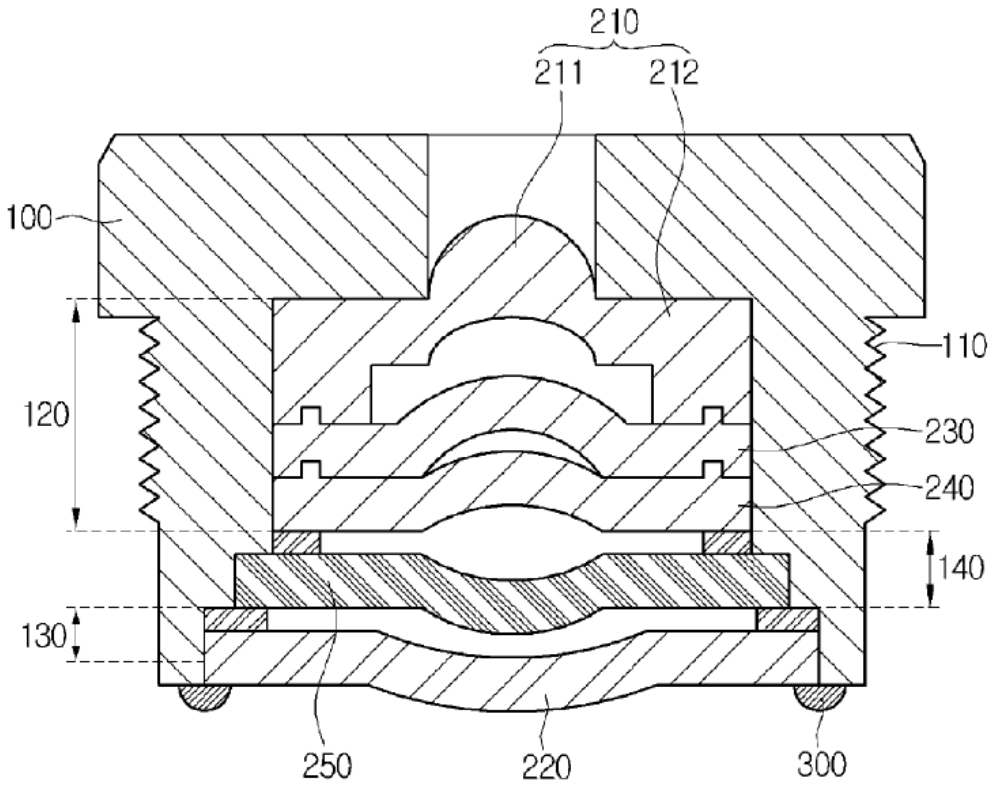


FIG. 3

Seung

Pub. No.: US 2013/0077183 A1
Pub. Date: Mar. 28, 2013



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Kang

Pub. No.: US 2015/0062727 A1
Pub. Date: Mar. 5, 2015

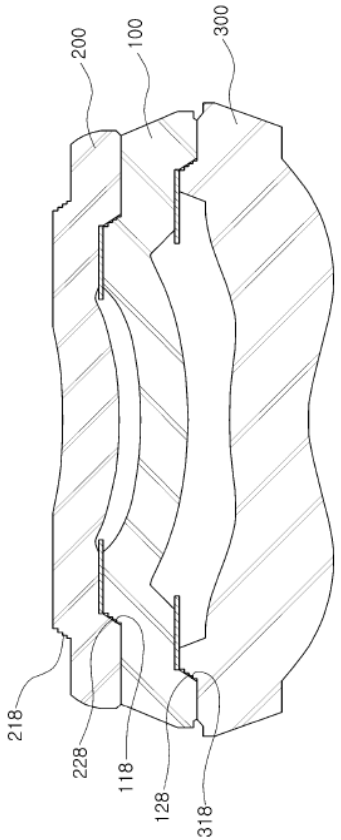


FIG. 7

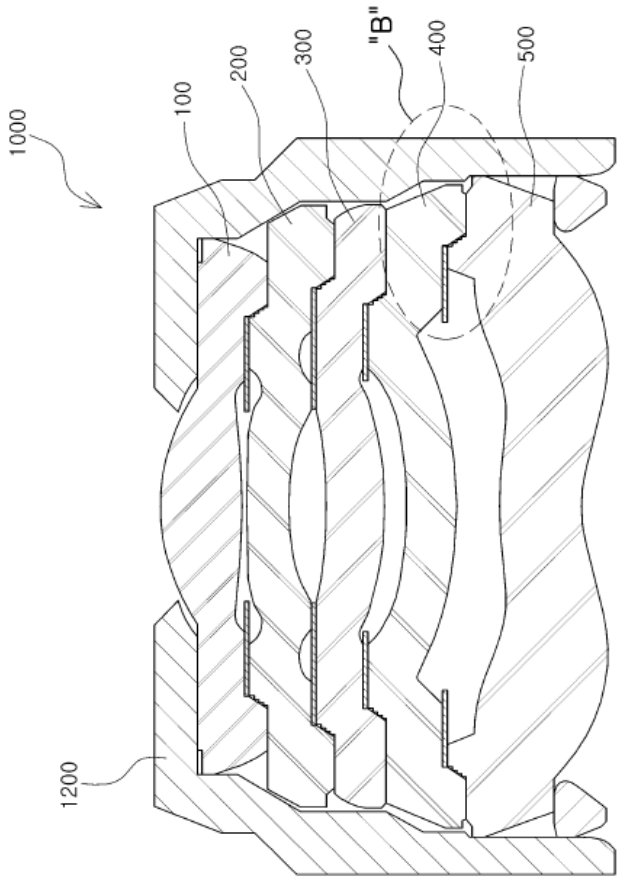
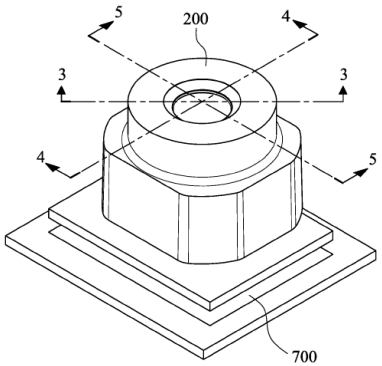


FIG. 10

Lin

Pub. No.: US 2016/0231526 A1
Pub. Date: Aug. 11, 2016



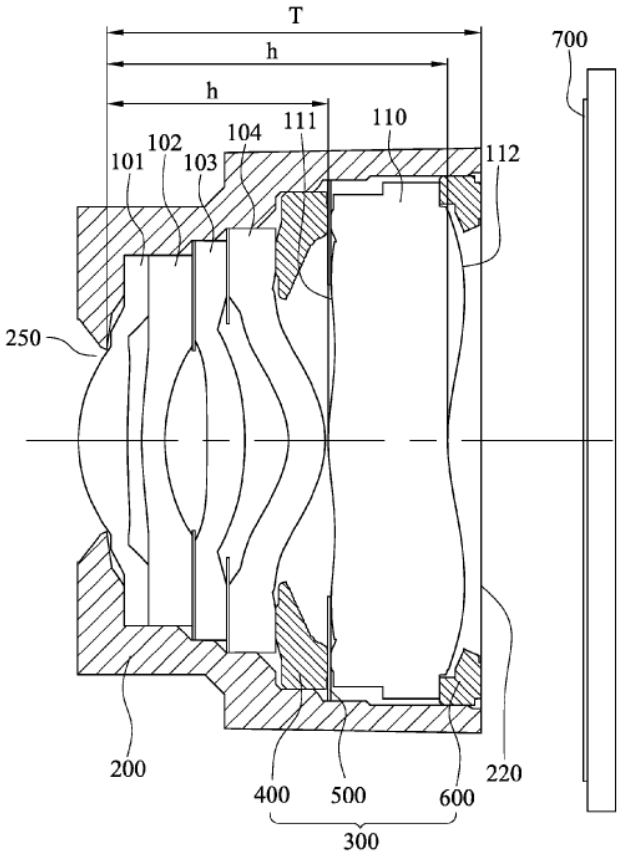


Fig. 5

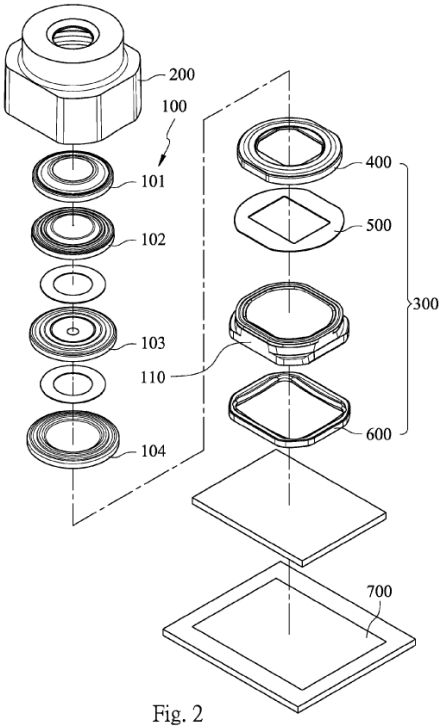


Fig. 2

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Tsai

Pub. No.: US 2018/0129011 A1
Pub. Date: May 10, 2018

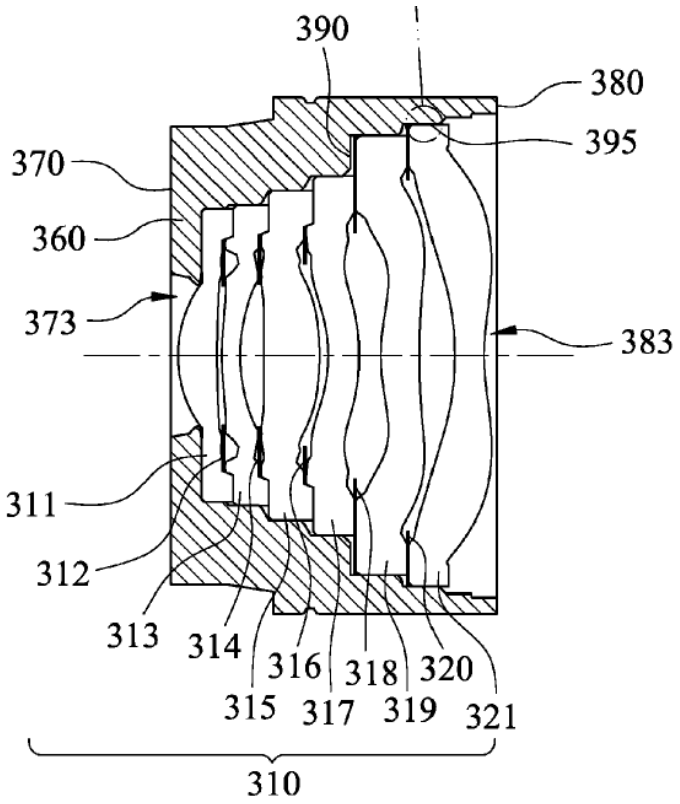

Fig. 3A

Suwon-Si

Pub. No.: US 2015/0241656 A1
Pub. Date: Aug. 27, 2015

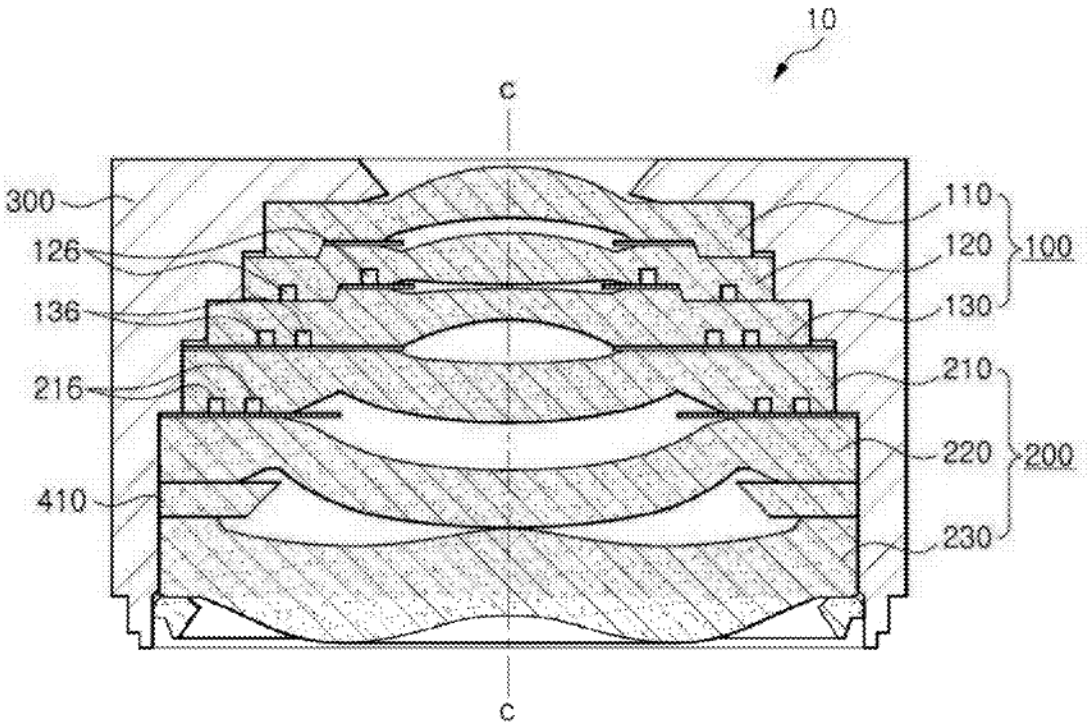

FIG. 12

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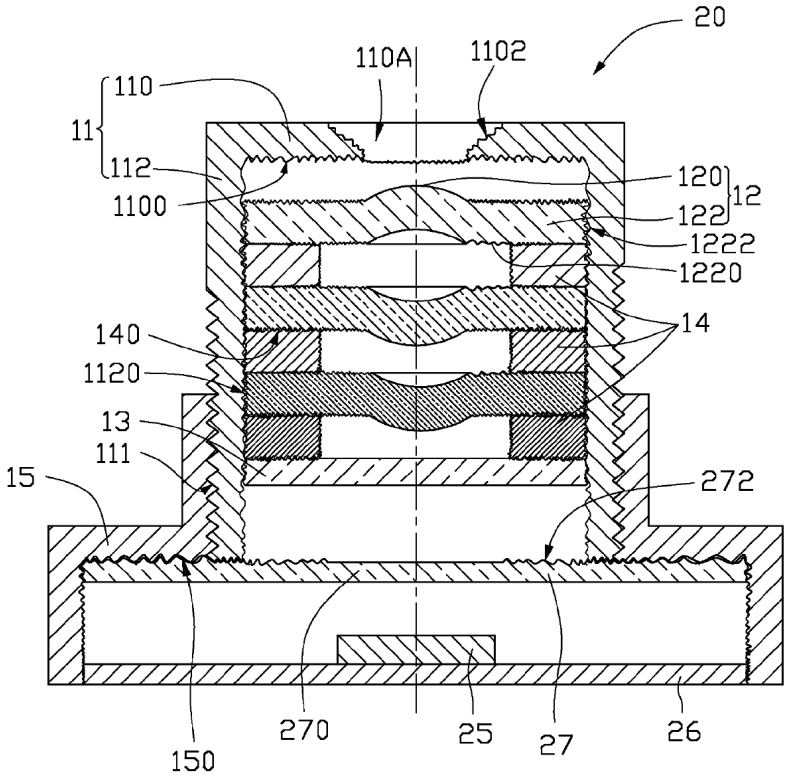
Chen

Pub. No.: US 2009/0147381 A1
Pub. Date: Jun. 11, 2009



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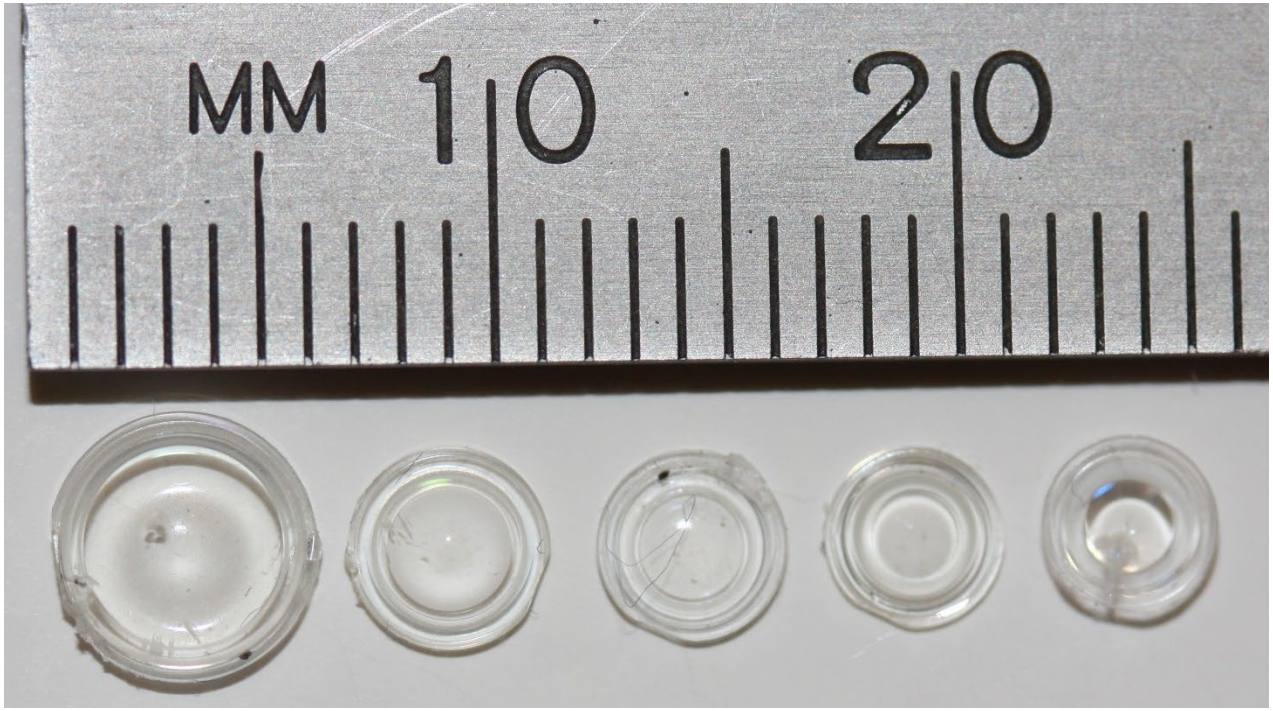
Rear camera I-phone 6



Manufacturing

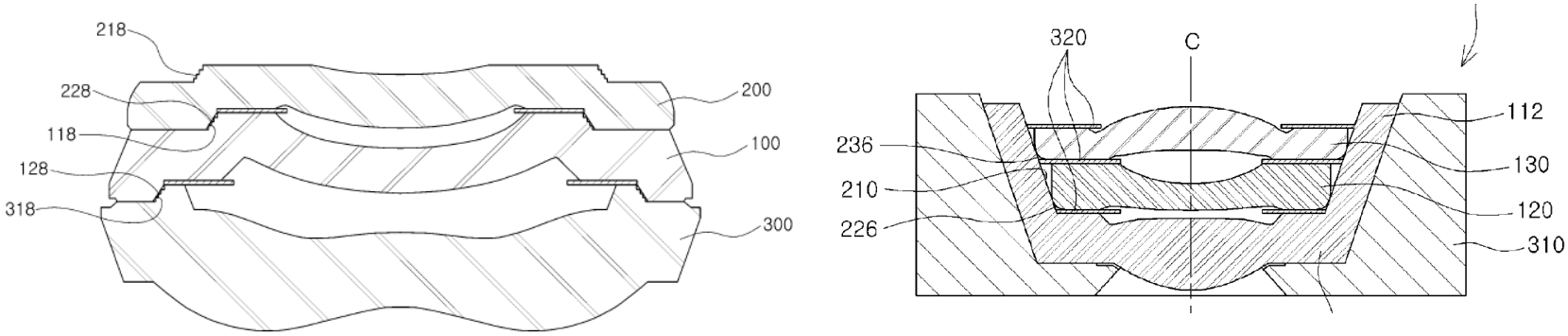


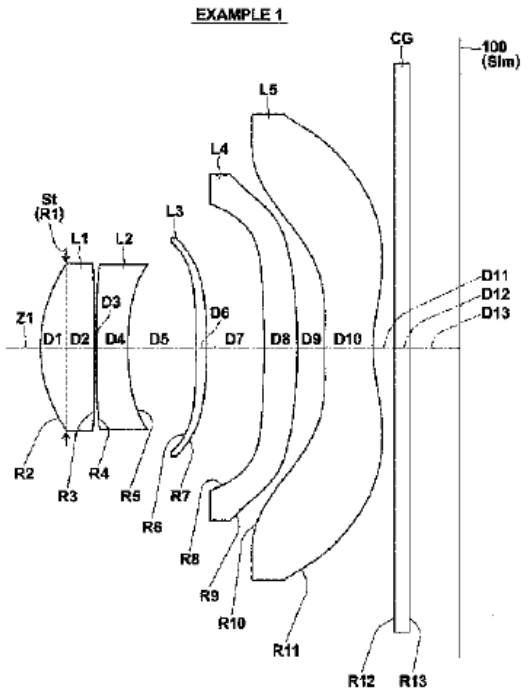
FIG. 7

For proper plastic flow and cooling, plastic lens manufacturers have some requirements for the aspect ratio of positive and negative lenses. Some guidelines are as follows: for positive lenses the ratio of lens central thickness to edge thickness should not be no more than 3.2, and the edge thickness should not be less than 0.32 mm; for negative lenses the ratio of the maximum thickness to the central thickness should not be larger than 2.7 and the central thickness should not be less than 0.27 mm.

The ideal lens for injection molding approaches a lens with parallel surfaces so that plastic flow, cooling, and shrinkage are uniform. For miniature lenses tolerances of 10 μm for thickness, decenter, total indicator runoff and lens tilt, are low; tolerances between 2 μm and 5 μm are medium and feasible to achieve in manufacturing, and tolerances between 0.5 μm and 2 μm are challenging to achieve and are met for some miniature optics.

Iwasaki

Patent No.: **US 9,678,310 B2**
Date of Patent: **Jun. 13, 2017**



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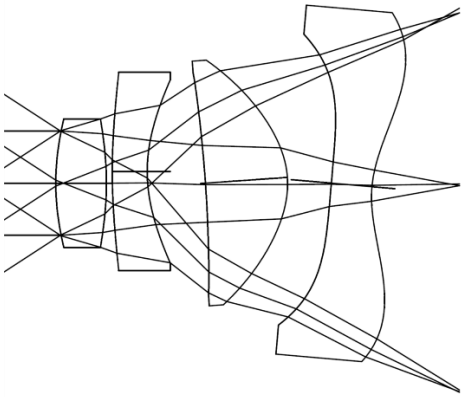
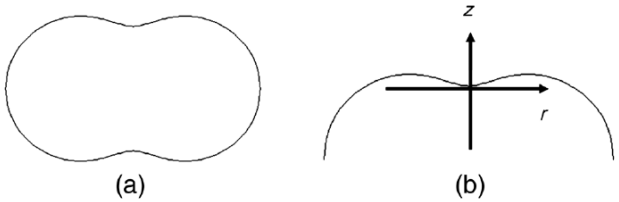
Desensitizing



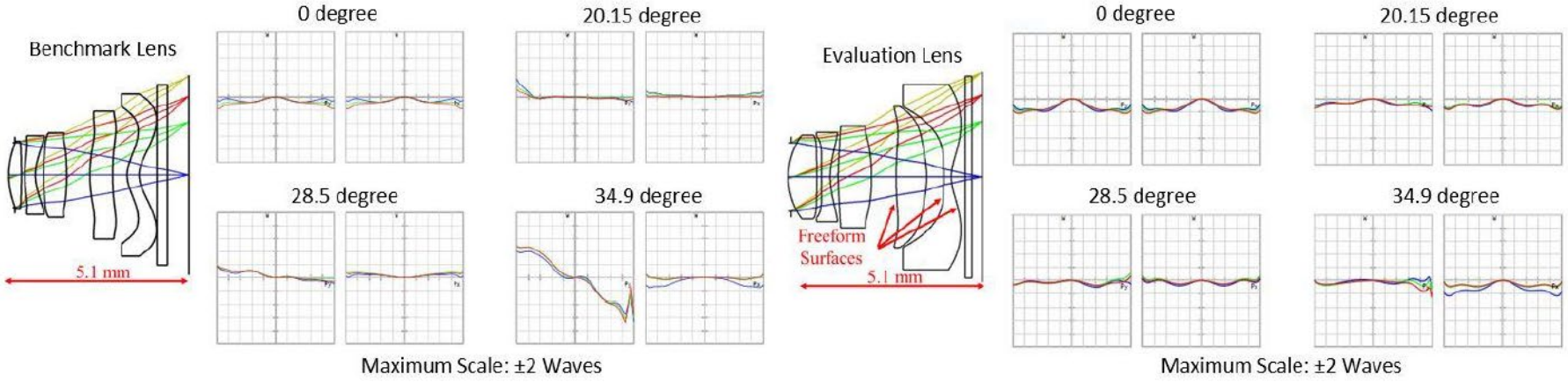
Lens configuration setting for desensitizing a Cooke triplet lens for lens wedge. Units are in mm and degrees.							
Configuration	1	2	3	4	5	6	7
Focal length	100						
Surface #1 tilt		0.1º					
Surface #2 tilt			0.1º				
Surface #3 tilt				0.1º			
Surface #4 tilt					0.1º		
Surface #5 tilt						0.1º	
Surface #6 tilt							0.1º

Choice of surface



$$S(r) = b - \sqrt{\frac{b^2 - 2r^2 + \sqrt{b^4 + 4(a^2 - b^2)r^2}}{2}}$$

$$z_p(r) = A_1 S_1(r) + A_2 S_1^2(r) + A_3 S_1^3(r) + B_1 S_1(r) + B_2 S_1^2(r) + B_3 S_1^3(r),$$



Miniature Camera Lens Design with a Freeform Surface

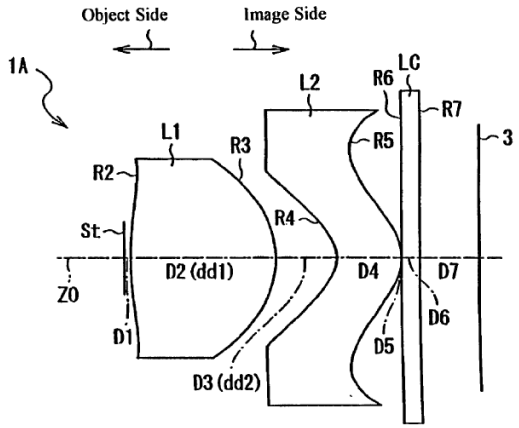
Yufeng Yan and Jose Sasian

College of Optical Sciences
THE UNIVERSITY OF ARIZONA

Aspheric coefficients

Shinohara

Even and odd
Aspheric surfaces



Pub. No.: US 2003/0117723 A1
Pub. Date: Jun. 26, 2003

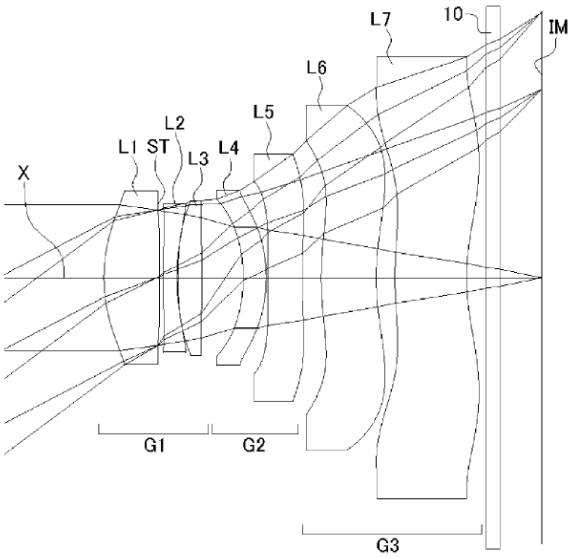
TABLE 6

#	C	K	A_4	A_6	A_8	A_{10}
2	0.2416	−16.7875	6.3491E−03	−5.5390E−03	3.1005E−06	5.7561E−07
3	−0.8046	−0.9488	−3.4059E−02	−1.6547E−04	−5.2245E−07	−1.3727E−09
4	−2.0019	−0.4916	1.5323E−02	7.4362E−05	2.4722E−07	6.9822E−10
5	−1.6571	−0.7550	3.1674E−02	4.9464E−04	2.5648E−05	3.1273E−07

Aspheric coefficients

Kubota

Patent No.: **US 9,146,380 B2**
Date of Patent: **Sep. 29, 2015**



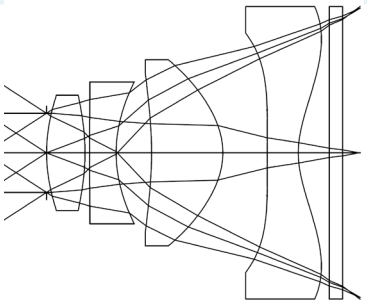
Aspheric Surface Data
First Surface
$k = 0.000, A_4 = -2.995E-03, A_6 = -1.855E-04, A_8 = -2.472E-04, A_{10} = -3.907E-06, A_{12} = -5.270E-07, A_{14} = 2.761E-07, A_{16} = -1.217E-09$
Second Surface
$k = 0.000, A_4 = 1.174E-02, A_6 = -1.391E-02, A_8 = 5.212E-03, A_{10} = -9.563E-04, A_{12} = 7.839E-05, A_{14} = -2.213E-06, A_{16} = 5.641E-08$

f = 9.57 mm, Fno = 2.4, ω = 32.1°
Unit: mm

Fourth Surface
$k = 0.000, A_4 = 1.333E-02, A_6 = -2.008E-02, A_8 = 7.838E-03, A_{10} = -1.302E-03, A_{12} = 7.691E-05, A_{14} = 5.904E-07, A_{16} = -5.003E-07$
Fifth Surface
$k = 0.000, A_4 = 6.851E-03, A_6 = -1.313E-02, A_8 = 3.616E-03, A_{10} = -2.531E-04, A_{12} = -2.370E-05, A_{14} = -1.000E-05, A_{16} = 1.564E-06$
Sixth Surface
$k = 0.000, A_4 = 1.103E-02, A_6 = -2.591E-03, A_8 = 1.170E-03, A_{10} = -4.329E-05, A_{12} = -5.911E-06, A_{14} = 2.463E-06, A_{16} = -1.368E-06$
Seventh Surface
$k = 0.000, A_4 = -1.065E-03, A_6 = 2.211E-03, A_8 = 8.593E-04, A_{10} = -4.613E-04, A_{12} = 7.895E-05, A_{14} = 7.220E-06, A_{16} = -5.043E-06$
Eighth Surface
$k = 0.000, A_4 = -1.547E-02, A_6 = 2.513E-03, A_8 = -2.149E-05, A_{10} = -2.485E-04, A_{12} = -1.856E-05, A_{14} = 1.073E-07, A_{16} = 1.527E-06$
Ninth Surface
$k = 0.000, A_4 = -6.920E-03, A_6 = 1.871E-03, A_8 = 8.894E-05, A_{10} = 1.388E-06, A_{12} = -2.970E-05, A_{14} = -1.020E-06, A_{16} = 2.309E-06$
Tenth Surface
$k = 0.000, A_4 = -8.230E-03, A_6 = -9.253E-04, A_8 = -7.779E-06, A_{10} = 6.194E-06, A_{12} = -1.505E-06, A_{14} = 5.207E-07, A_{16} = -3.481E-08$
Eleventh Surface
$k = 0.000, A_4 = -1.020E-02, A_6 = -6.061E-04, A_8 = 1.202E-04, A_{10} = 1.683E-06, A_{12} = 1.154E-07, A_{14} = -4.525E-08, A_{16} = 7.646E-11$
Twelfth Surface
$k = 0.000, A_4 = -1.374E-02, A_6 = -3.962E-04, A_8 = -3.784E-05, A_{10} = -2.372E-06, A_{12} = 1.515E-07, A_{14} = 2.223E-08, A_{16} = -2.404E-09$
Thirteenth Surface
$k = 0.000, A_4 = -1.172E-02, A_6 = 2.665E-05, A_8 = 2.272E-05, A_{10} = -1.026E-06, A_{12} = -5.260E-09, A_{14} = 1.463E-09, A_{16} = -2.585E-11$
Fourteenth Surface
$k = 0.000, A_4 = -2.216E-02, A_6 = 1.317E-03, A_8 = -2.194E-05, A_{10} = -2.470E-07, A_{12} = 6.753E-10, A_{14} = 1.105E-10, A_{16} = 1.524E-11$
Fifteenth Surface
$k = -1.551E+01, A_4 = -9.918E-03, A_6 = 3.875E-04, A_8 = -1.268E-05, A_{10} = 1.234E-07, A_{12} = 9.762E-09, A_{14} = -5.202E-10, A_{16} = 6.871E-12$

Prescription table

Example of a four lens element design for a mobile phone lens. F=5.0 mm, FOV=+/-32º, TTL/f=1.4, F/2.8. CRA=30.6º.					
Surface	Radius	Thickness	Plastic	K	A_4
STOP					
2	3.5432.72	0.87	E48R	-3.2457	
3	-4.57977	0.1		-11.7213	
4	126.2449	0.6	OKP4	0.0	
5	3.013807	0.8		-0.9977	-2.533E-3
6	-8.81693	1.61	E48R	0.0	4.161E-3
7	-1.61409	1.0		-2.2699	-0.0126713
8	72.73421	0.7	OKP4	0.0	-0.0100888
9	2.101288	0.7		-6.3020	-6.073E-3
10	Plano	0.3	BK7		
11	Plano	0.4			
Image					



Materials

Properties of some plastics used in mobile phone lenses				
Code	n_d	v	γ	ρ
480R	1.525	55.95	$+1.44 \times 10^{-4}$	1.01
E48R	1.531	56.04	-2.62×10^{-4}	1.02
F52R	1.534	57.09	-2.21×10^{-4}	1.01
OKP4	1.607	26.90	-3.44×10^{-4}	1.20
OKP4HT	1.632	23.33	-2.72×10^{-4}	1.24

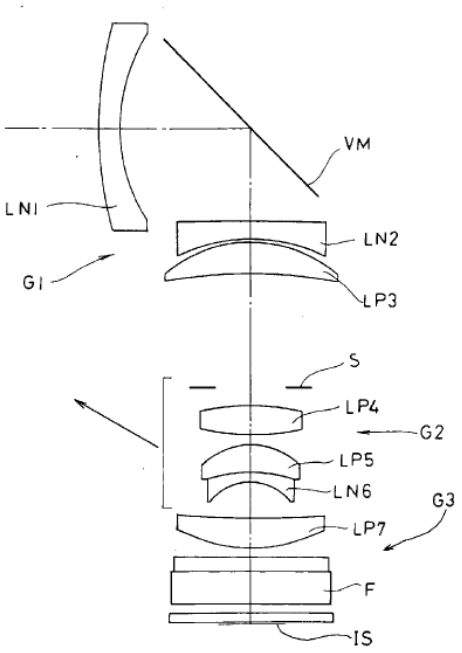
- Water absorption
- Light scattering and haze
- Transmission
- CTE
- Dn/dt
- Opto-thermal coefficients
- Durability
- Birefringence

Links to optical plastics vendors:

http://www.ogc.co.jp/e/products/fluorene/okp.html
https://www.zeonex.com/Optics.aspx.html#glass-like

Zooms/folded

Pub. No.: US 2007/0258711 A1
Pub. Date: Nov. 8, 2007



Pub. No.: US 2016/0231540 A1
Pub. Date: Aug. 11, 2016

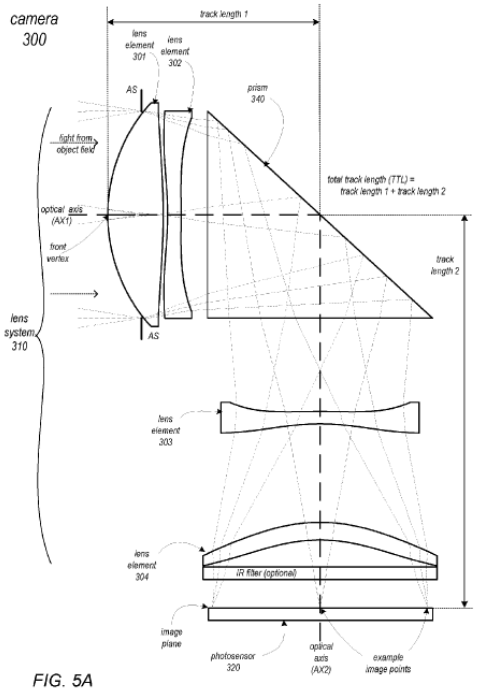
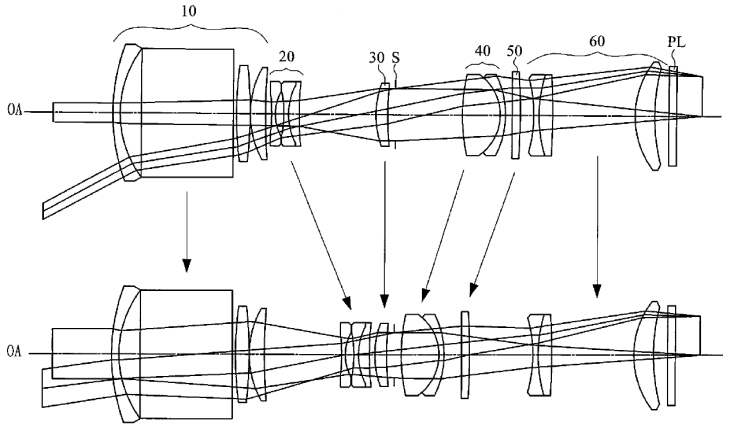


FIG. 5A

Patent No.: US 7,626,767 B2
Date of Patent: Dec. 1, 2009



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Papers

1. P. Clark, “Lens design and advanced function for mobile cameras,” Chapter 1, in *Smart Mini-Cameras*, Galstian, T. V. Editor, CRC Press, Boca Raton, FL, (2014).
2. Jane Bareau, Peter P. Clark, "The optics of miniature digital camera modules", Proc. SPIE 6342, International Optical Design Conference 2006, 63421F (25 July 2006); doi: 10.1117/12.692291; https://doi.org/10.1117/12.692291
3. Peter P. Clark, "Mobile platform optical design", Proc. SPIE 9293, International Optical Design Conference 2014, 92931M (17 December 2014); doi: 10.1117/12.2076395; https://doi.org/10.1117/12.2076395
4. M. Schaub, “The design of plastic optical systems,” SPIE Press, Vol. TT80, 2009.
5. Reshidko, D., & Sasian, J. (2015). Optical analysis of miniature lenses with curved imaging surfaces. *Applied Optics*, *54*(28), E216-E223. DOI: 10.1364/AO.54.00E216
6. Yufeng Yan, Jose Sasian, "Miniature camera lens design with a freeform surface", Proc. SPIE 10590, International Optical Design Conference 2017, 1059012 (27 November 2017); doi: 10.1117/12.2292653; https://doi.org/10.1117/12.2292653