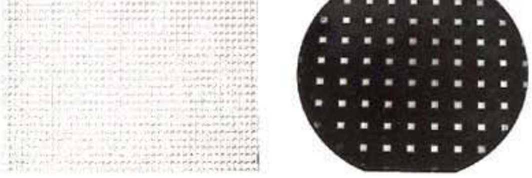
Nikon
Ultra-Micro-Nikkor Lenses

Ultra-Micro-Nikkor lenses---
their resolution began a revolution

The revolutionary advances made by the electronics industry in mass-producing IC and LSI miniaturized circuits are due in no small way to the photographic industry's own dramatic advances in this regard. For a basic part of such mass production is the preparation of photomasks—negatives measuring 5 sq.cm, with a central 3–4 sq.cm area covered by several hundred micropatterns of the same configuration (Fig. 1).
Finished IC and LSI quality derives directly from the degree of precision reflected by these photomasks. Similarly, the photomasks depend for their accuracy on the lenses used to print them. These lenses need ultra-high resolving power; so do those used to project the image of the photomask onto the silicon wafer from which the final product is manufactured.
That is why for this highly specialized field of super-microphotography, the Ultra-Micro-Nikkor lenses described in this brochure had to be produced. They are without peer in the world, and they offer electronics manufacturers unrivaled savings, while allowing them to maintain the precision necessary in the mass production of IC and LSI miniaturized circuits.

Fig. 1 Photomask & wafer




Ultra-Micro-NIKKOR 155mm F 4
NIKON
Ultra-Micro-NIKKOR
NIKKOR 1:4 f=155mm

History of the Ultra-Micro-Nikkor

The resolving power of a lens is very closely related to its aperture: lenses with small apertures cannot be expected to give really high resolution. Where super-high resolution lenses are concerned, there are no short-cuts, so it was not until 1961 that the first Ultra-Micro-Nikkor lens—a 105mm f/2.8 e-line type —was born.

Problems had been very great, but they were overcome by introducing extremely precise production techniques and by limiting the picture angle and the range of chromatic-aberration corrections to the narrow wavelength band of green light to which the ultra-high resolution, orthochromatic photoplate sensitizer responds.

The ensuing age of integrated circuitry prompted the birth of other Ultra-Micro-Nikkor lenses, each new one keeping pace with the fast-moving world of electronics manufacturing. The limit of resolving power theoretically attainable in optics was reached when the 30mm f/1.2 lens was born, resulting in Nikon's receipt of an award from the Director of the Science and Technology Agency in 1965.

But the advent of even more sophisticated IC technology involving line widths of only 1μ made silver halide emulsions too thick for practical purposes, so chrome-plated photomasks, with photoresist as their photo-sensitizer, were developed. So, too, was the h-line Ultra-Micro-Nikkor group of lenses—designed to meet the new wavelength requirements.

The 225mm f/1:0g and the 300mm f/1.4g Ultra-Micro-Nikkor projection-printing lenses were developed to meet advances in IC productive technology and to solve the problem caused by conventional contact printing where photomasks and wafers inevitably become scratched. But in 1:1 projection printing, mask and wafer do not come into physical contact so there is no chance of abrasion. Two happy by-products are higher productive capacity and lower costs.

Doubtless tomorrow's technological advances will bring in their wake new problems to be solved and, as in the past, Nikon is ready to meet them when they arise.

Two groups of Ultra-Micro-Nikkor lenses

Broadly classified according to their photo-sensitive materials, there is sufficient variety in the two groups of Ultra-Micro-Nikkor lenses to match the varying picture sizes, reduction ratios, and other technical requirements that may arise.

Group 1:
e-line Ultra-Micro-Nikkor

Lenses in this group are used mainly with high resolution photo plates of silver halide emulsion, using e-line.

Thanks to their minimal aberration and consequent super-high resolving power, these lenses come extremely close to the ideal.

Spectral wavelength

e-line (λ: 546.1mμ)

Effective f/number	Resolving power (lines/mm)
1.0	1501
1.2	1251
1.4	1072
2	750
2.8	536
4	375
5.6	268
8	188
11	136
16	94
22	68

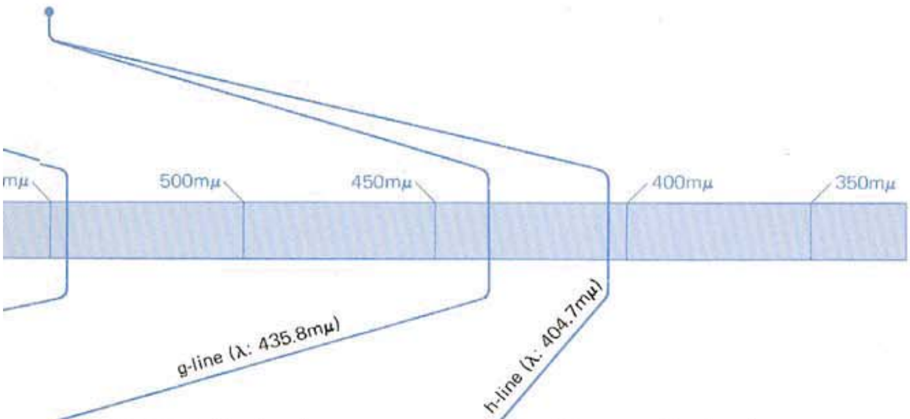
Lens speed and its relation to resolution

The diffraction theory of light imposes theoretical limitations on the resolving power of a lens, the limit depending on the lens speed (f/number). This limit can be determined by the lens speed, magnification ratio and wavelength used. In other words, the resolving power at the center portion of an aberration-free lens has the following relationship:

$$\text{Resolving power} = \frac{1}{1.22\lambda Fe} \text{(lines/mm)}$$

Group 2:
g-line and h-line Ultra-Micro-Nikkor
Lenses in this group are required when photo-resist (photo-sensitive resin) is used as the sensitizer. Using a shorter wavelength than the e-line group of lenses, they provide a higher resolving power.

Both the 225mm and 300mm Ultra-Micro-Nikkor lenses are used for photomask copying or for projection printing of photomask images onto wafers. They can print lines as fine as only 2μ over an entire picture area without image distortion; their lens construction is perfectly symmetrical.



Resolving power (lines/mm)	Resolving power (lines/mm)
1881	2025
1567	1688
1343	1447
940	1013
672	723
470	506
336	362
235	253
171	184
118	127
85	92

where λ = wavelength used (in mm) and Fe = effective f/number, which is related to the f/number (F) under formula Fe = F (1 + M), where M is the photographing magnification. From this formula, the faster the lens speed, the higher the resolution. Similarly, the shorter the wavelength used, the higher the resolution. The above chart shows the relationship between the effective f/number, operating wavelength (λ) and resolving power when calculated from this equation.

Applications for Ultra-Micro-Nikkor Lenses

Although developed primarily for the production of photomasks for high-frequency semiconductor elements (diodes, transistors, IC's and LSI's), Ultra-Micro-Nikkor lenses are also useful for photo-etching, for production of evaporation masks by electroforming and of photomasks of filter, mesh or other minute parts, and for the direct projection printing of photomasks onto plates coated with photo-resist.
Ultra-Micro-Nikkor lenses are also ideal for making lens testing charts and producing glass plates on which complex micropatterns for optical instruments or inspection equipment are printed.
Another important application for these lenses is the ultra-microphotographic reproduction of books.
Ultra-microphotography answers the needs of those who must be provided with a vast amount of data occupying a minimal amount of space. It is useful too for those computer systems which require ultra-high density storage of information.
One additional application of these Ultra-Micro-Nikkor lenses has been their use in testing the resolving power of everyday film.

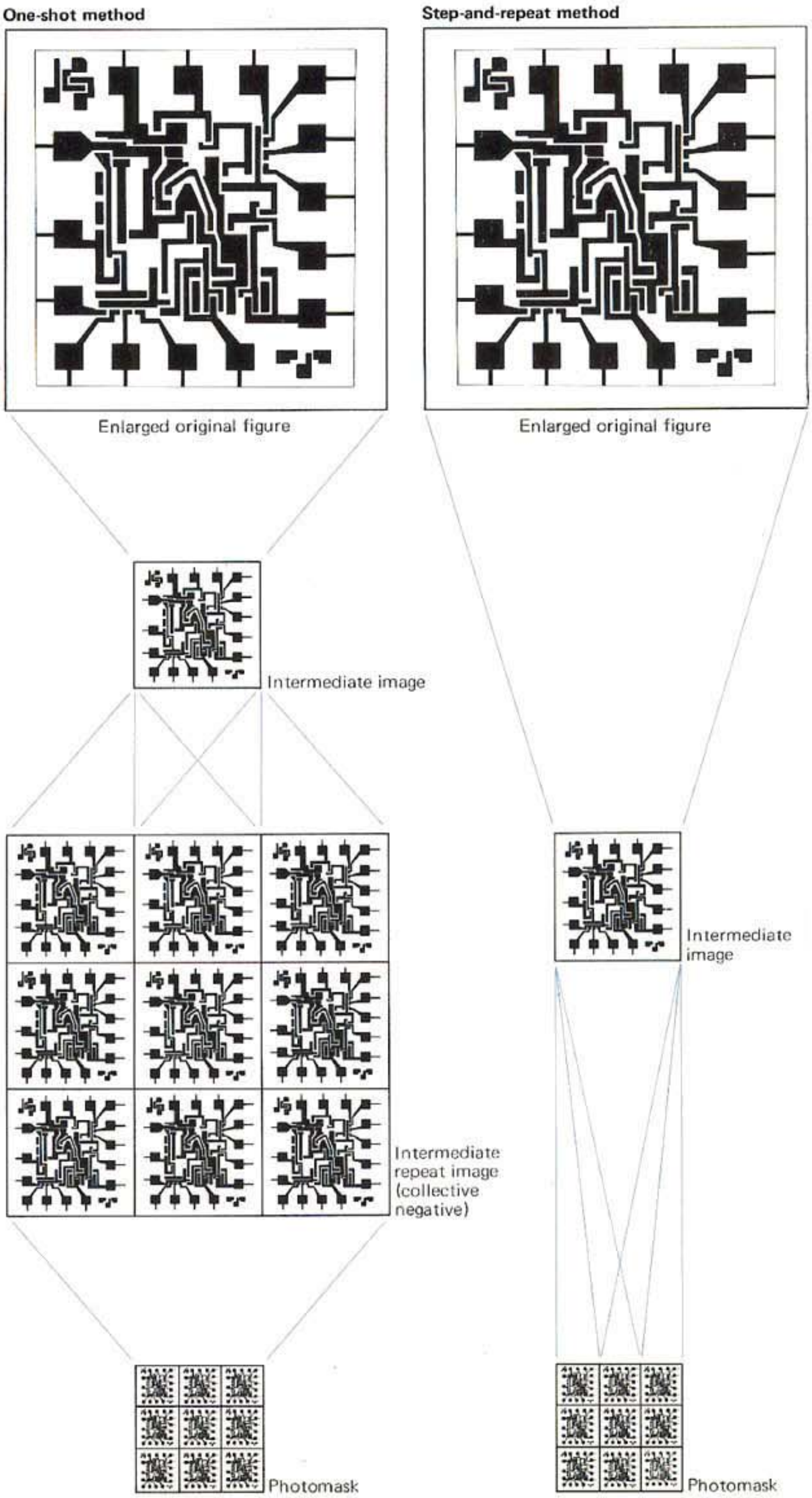
Ultra-microphotographic methods of producing photomasks and wafer prints

Photomask production

An ultra-microphotographic reduction system that can make pattern reductions 1/100th of the original size or smaller is used to make photomasks. The procedure usually involves two steps. First, an intermediate negative is made from the large original; then the photomask is made from this intermediate negative. This latter step involves one of two distinct methods—the one-shot method or the step-and-repeat method.

In the case of the one-shot method, the intermediate negative is repeatedly printed on a large photoplate or sheet film (non-expanding and non-contracting) Thus a collective negative is produced and this in turn is reduced to the reduction ratio required by the photomask.

In the step-and-repeat method, the intermediate negative pattern is reduced and projected repeatedly onto a photoplate of high resolution by a lens that is moved laterally and longitudinally in regular sequence across the dryplate, which when completed becomes the photomask.



Wafer printing

There are two methods for 1:1 reproduction of photomasks or for printing the photomask image onto a wafer—the contact printing method and the optical projection system. The latter is by far the better of the two and results are enhanced by the 1:1 projection of an Ultra-Micro-Nikkor lens. Its principal advantage is the lack of any contact, and therefore any wear, of photomask and wafer. Contact-printing, though requiring no projection lens, suffers from many disadvantages including contact and consequent wear of photomask and wafer.

Projection printing advantages

Projection printing is so superior to contact printing of wafers from photomasks that it has become virtually a prerequisite for the economical, fully automated manufacture of IC's and LSI's in the electronics industry. Its principal advantages are:

- Extended life of mask and wafer due to absence of any physical contact between them.
- Maladjustment of mask and wafer due to friction eliminated.
- Fine-focus and print sharpness unaffected by any wafer surface unevenness because the mask never comes into contact with the wafer.
- More economical production of IC's and LSI's.

Practical consideration

Illumination and sensitivity of materials

■ Illumination for e-line Ultra-Micro-Nikkor lenses

Three distinct methods of illumination can be used, though the first of those described below is preferable as the easiest way of obtaining the necessary monochromatic green light of 546mμ wavelength.

1. This light may be obtained simply by illuminating the photomask with a high-pressure mercury lamp and by attaching a filter exclusively designed for the Ultra-Micro-Nikkor.
2. A yellow filter cutting off wavelengths below 520mμ or 530mμ on the light source side will also suffice, because ordinary ultra-high resolution photoplates on the market are orthochromatic and insensitive to wavelengths above 570mμ.
3. An ordinary incandescent light (tungsten, halogen, xenon, etc.) may also be used with a sharp cutoff filter; in this case, the light will not be pure monochromatic but it will be green within the narrow wavelength band of 520 to 560mμ and the Ultra-Micro-Nikkor e-line lenses are sufficiently corrected for chromatic aberration to tolerate this.

■ Illumination for g-line or h-line Ultra-Micro-Nikkor lenses

A mercury lamp or ultra-high-pressure mercury lamp should be used as the light source. Light wavelengths shorter than 400mμ should be excluded because the photo-resist is sensitive to them, but wavelengths longer than 500mμ do not matter because the photo-resist is insensitive to them (Figs. 2 and 3). So the combined use of a mercury lamp and UV filter with photo-resist as the sensitizer enables usage at both g- and h-line wavelengths.

If h-line wavelength only is to be used, then an h-line interference filter should be employed.

If g-line wavelength only is to be used, a g-line interference filter should be used. Or alternatively, a sharp cutoff filter absorbing light of wavelength shorter than 410mμ should be used.

■ 1:1 projection printing illuminator

A special illuminator is required for 1:1 projection printing that involves the printing of the pattern image on a photomask onto a plate coated with photoresist. Because of the photo-resist's very narrow latitude, the illuminator must provide high contrast and uniform lighting over the entire image area irrespective of any variation in image shape that may be present.

The Nikon 1:1 Projection-Print Illuminator is specially designed for the job. It employs partial coherent illumination suited for use with the Ultra-Micro Nikkor 300mm f/1.4g or 225mm f/1.0g lens. It consists of a spherical mirror, heat absorbing filter, diffuser and condenser lens and can also provide fully coherent illumination if the diffuser is removed.

Fig. 2

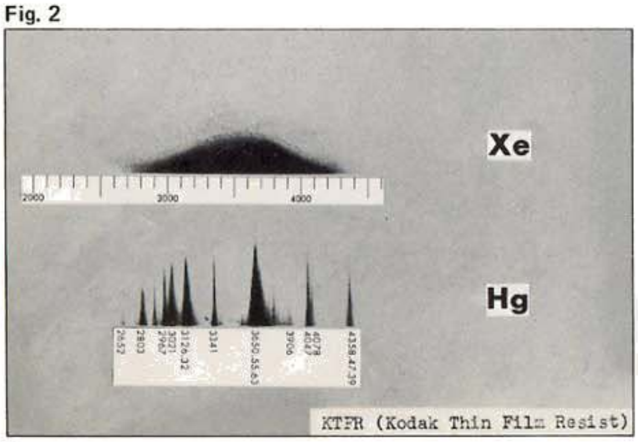
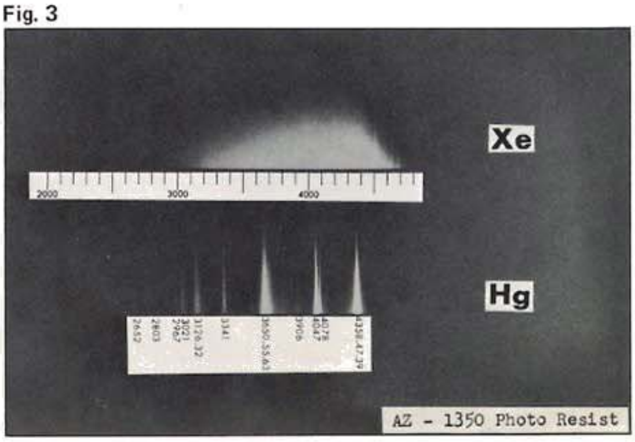


Fig. 3



Photographic magnification

Ultra-Micro-Nikkor lenses should be used according to their specific magnifications. As described earlier, the original is reduced in two stages to arrive at photomask size: first, an intermediate negative plate is made; then, an Ultra-Micro-Nikkor lens is used to reduce it further to the size of the photomask to be made. Thus the product of magnifications of the first two stages equals the total magnification. So the choice of magnification for the first stage (and the choice of lens which need not be an Ultra-Micro-Nikkor for this stage) will decide what the total magnification will be, because the second stage magnification is inflexible, depending solely on the Ultra-Micro-Nikkor lens used.

When using an Ultra-Micro-Nikkor for the one-shot method to make an intermediate negative plate, the guaranteed resolution cannot be obtained unless the lens is used according to its specified magnification. Therefore the total magnification cannot be freely selected.

	Photomask		Secondary reduction		Intermediate negative		Primary reduction	
	Diameter of image area (mm)	Resolving power (lines/mm)	Lens to be used	Reduction ratio	Diameter of image area (mm)	Minimum resolving power (lines/mm)	Lens to be used	Reduction ratio
One-shot method	28	400	125mm f/2.8	1/25X	700	16	Select an appropriate Nikon industrial lens—Micro-Nikkor, EL-Nikkor, Fax-Nikkor, or Fax-Ortho-Nikkor.	
	64	200	135mm f/4	1/25X	1600			
	50	330			1250	14		
	80	200	155mm f/4	1/10X	800	20		
	56	300			560	30		
	80	200	165mm f/4	1/40X	3200	5		
Step-and-repeat method	8	600	28mm f/1.8e	1/10X	80	60	Select the most appropriate one according to the size of the intermediate negative in use.	
	7	650			70	65		
	6	700			60	70		
	2	1250	30mm f/1.2	1/25X	50	50		
	14	500	50mm f/1.8e	1/5X	70	100		
	12	600			60	120	Micro-Nikkor 70mm f/5	1/5–1/30X
	12	500	55mm f/2	1/4X	48	125		
	8	750	28mm f/1.8h	1/10X	80	75	Micro-Nikkor 150mm f/5.6	1/5–1/30X
	7	800			70	80	Ultra-Micro-Nikkor 135mm f/4	1/25X
	6	900			60	90		
	3	1300	30mm f/1.2h	1/25X	75	52	Ultra-Micro-Nikkor 155mm f/4	1/10X
	2	1600			50	64		
	14	650	50mm f/1.8h	1/5X	70	130	Ultra-Micro-Nikkor 165mm f/4	1/40X
	10	800			50	160		

e-line filters

These filters have been specially designed to develop the performance of Ultra-Micro-Nikkor lenses to the fullest extent. They consist of two separate filter glasses, each with differing wavelength transmission factors, but bonded together and responsive to the wavelengths of the photo-sensitizer. In addition they are light-discriminatory, transmitting only that very narrow range of light around the e-line. Their planes feature perfect flatness and parallelism and will detract in no way from the ultimate excellent resolving power of any Ultra-Micro-Nikkor lens to which they are attached.

Attachment size	Applicable lens
40.5mm	28mm f/1.8, 30mm f/1.2, 55mm f/2
62mm	135mm f/4
72mm	125mm f/2.8, 155mm f/4

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