

On Some Proposals of Applying the Holographic Technique to Both the Semiconductor Junction Measurement and the Microelectronic Technology

1. An Examination of the Doping Concentration in the Junction

Measurement methods used hitherto to determine certain parameters of semiconductor junctions such as: refraction index, transmission index, absorption index and carrier concentration allowed to measure, principally, the mean values applying to the whole region of the junction. Scanning methods were, of course, also known, they enabled to measure the distributions of the said parameters yet, they are encumbered with a fundamental disadvantage i.e. — the dependence of the measurement accuracy upon the spectral range employed, which results from diffraction limitations.

The scanning is realized with the help of a quasi-point light spot produced by focusing an earlier collimated light beam emerging from a thermal light source and adequately filtered to get a sufficiently good monochromacy. The diameter of the spot thus created can at best not be smaller than the wavelength λ of the light used. Consequently, the width of the scanning line produced on the sample by the scanning spot can not be better than λ , and thus the accuracy of scanning does not exceed λ . In this way any change in the wavelength is followed by a corresponding change in the scanning accuracy. This results in serious interpretation difficulties, if the results are to be compared with those obtained for different spectral ranges.

To make the measurement results independent of the spectral range used during the measurement a system is proposed, in which the measurement is carried out with the use of one fixed wavelength, while changes in the sample are produced by the radiation of various wavelengths.

Let the light beam from a laser source uniformly illuminate the sample surface S (see Fig. 1). As a result of reflection, diffraction and scattering appearing on the surface of the sample a part of the radiation tra-

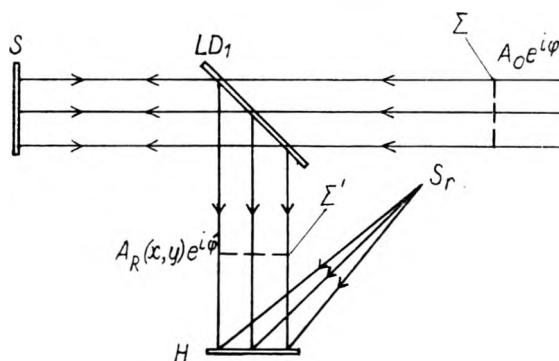


Fig. 1

vels back and, after being reflected from the light-dividing plate LD_1 , creates a wave-front Σ' propagating in the direction of surface H . All the information about the sample surface, which is being carried by the illuminating wave is coded in both the amplitude and phase distributions $A_R(x, y)$ and $\phi(x, y)$ in the wave-front (Fig. 1). By making the information wave U_0 to interfere with a reference wave U_r , being coherent with respect to U_0 , an interference field appears, which can be recorded on a photographic material in the form of a complex system of interference fringes. The information about the amplitude and phase distribution in the information wave is, in turn, coded in the form of both the contrast and spatial frequencies distribution of the fringes. Thus, a hologram of a sample presents information about the sample recorded interferentially [1]. By applying a routine reconstruction procedure with the reconstruction beam identical with the reference wave U_r a virtual image of the sample may be produced, which is positioned exactly in the place of the sample.

Now, suppose that there exist a definite spatial distribution of the doping concentration in the sample to be tested; the sample being a cross-microsection of a semiconductor junction. This distribution of the doping concentration is closely related to the complex refractive index distribution $n^* = n^*(x, y)$ in the sample and in particular at its surface. This distribution

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is, in turn, associated with the intensity reflection coefficient $R(x, y) = f(n^*)$ at the same surface in accordance with the formula

$$R = \left(\frac{1 - n^*}{1 + n^*} \right)^2, \quad (1)$$

where: $n^* = n(1 - ik)$, and n is a refractive index while k denotes an extinction coefficient. Thus, if a wave of a definite amplitude and phase falls upon the surface, exhibiting different values of n^* and consequently different values of R at different places, then the reflection will result in a modulated amplitude $A_r(x, y)$ and, in general, also a phase $\varphi(x, y)$.

When applying laser illumination and locating a perfect metallic mirror in place of the sample (for instance a free surface of quicksilver or galium) a hologram of a non-disturbed illuminating beam is performed. Next, the hologram of the sample is registered on the same photographic plate. As a result of the reconstructing procedure we obtain two beams interfering with each other and corresponding to the virtual images: one produced by the unperturbed wave and the other by the informational illuminating wave perturbed by interacting with the sample.

The contrast, shape and spatial frequency of the interference fringes are influenced by such factors as flatness and smoothness of the sample surface, reflection coefficient distribution and the accuracy of positioning at the same place of both the examined and reference surfaces. It is of course, of first importance to ensure a proper flatness and smoothness of the tested sample to assure an undisturbed measurement. Besides, a regulation means have to be supplied to assure a high accuracy of position reproductivity when replacing the reference surface by the examined surface and vice versa. A precise adjustment of the angle between these surfaces is also necessary for the holographic interferometer to operate in both the zero field and the fringe field of the requested sensitivity.

The holographic interferometer described above is a double exposure device [2]. For the purpose of junction examination a holographic interferometer, working in real time, is preferable. A system of that kind is realized in such a way that a hologram of unperturbed illumination beam (i.e. a hologram of a reflecting mirror surface) is produced first and, after being chemically developed, is located again in the previous position, while the sample to be examined is positioned in place of the reference surface. The interference in this system occurs between the information beam perturbed on the object and the illuminating beam reconstructed from the hologram. If an interference image thus obtained exhibits too little

information it is possible to increase the deformation of the information wave by direct action on the examined sample until an effect is achieved, which is sufficiently great to be measured. This action may be of a thermal, pressure or electromagnetic type; the radiative type being specially recommended. By introducing a light-dividing plate to the system presented in Fig. 2 an irradiation of the examined sample becomes

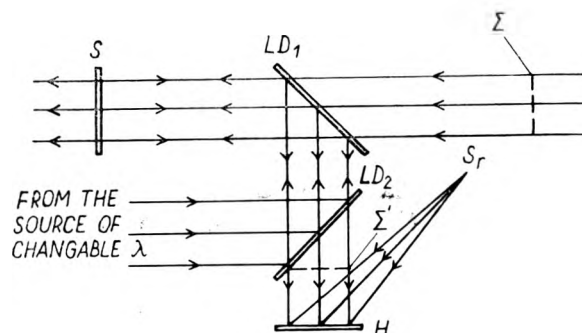


Fig. 2

possible without any changes in the holographic interferometer operation. Local changes in the sample caused by the irradiation may be continuously observed with the help of the interferometer by changing the wavelengths and intensity of the irradiation; the changes being closely related to the local changes in the doping concentration.

2. Holographic Technique of Masking

An employment of holography in contactless production of integrated microcircuits was one of the first technological applications of holography [3, 4]. In this respect the fundamental problem is the limited resolution to be achieved in the imaging process and in the diffraction efficiency of the holograms. The available resolution does not exceed that of conventional optical systems, which are, however, more expensive.

As a shortening of the exposure time of the real image of the microcircuit on the resistive layer is advantageous it is attempted to maximize the diffraction efficiency of the imaging process and simultaneously to regain the maximum of radiation lost in both the zero order and the remaining orders of diffraction. An improvement in resolution is also attempted. All requirements may be fulfilled by applying the system proposed by RIGLER [5]. He recommended the employment of a hologram with a metallic mirror layer deposited on it as one of the mirrors in the laser resonator. The power density within the resonator is greater by one or two orders of magnitude than that

outside the resonator. The power density in the image reconstructed in this way is therefore much greater. Moreover, the zero-order beams are not wasted but maintain the laser action. This type of reconstruction bears the features of reactive imaging [6], which results in considerable improvement of the resolution in the image and even in superresolution, which is a better resolution than these determined by the known diffraction limitations.

It may be shown that the reconstruction of the "holographic laser resonator mirror" type as well as the reactive imaging are some extreme cases of the natural tendency consisting in transition from the single-beam reconstruction to the multiple-beam reconstruction. An analogy to the two-beam and multiple-beam interference is obvious. While in the transition from the two-beam interference to the multiple-beam interference the spatial distribution of the intensities in the interference pattern changes from the $\cos x$ type to the distribution described by the Airy function,

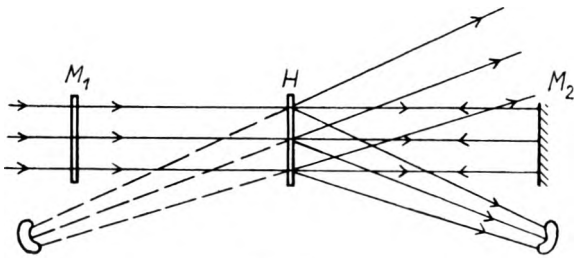


Fig. 3

which considerably improves the resolution, the transition from the single-beam reconstruction to the multiple-beam reconstruction results in changes of energy distribution reconstructed in the image points from a certain type of quasigaussian distribution to that of Airy type. Thus the reconstructed points creating the finest microcircuit traces exhibit no diffusion spread. This can improve the precision of the production.

The transition to the multiple-beam reconstruction may be realized by placing the hologram between two auxiliary mirrors M_1 and M_2 (Fig. 3). The role of

may be expected. A two identical systems for the multiple-beam reconstruction with different auxiliary mirrors configuration are presented in Fig. 4 (a and b). These mirrors operate independently of the distance between them, provided there occurs no blending of the diffracted beams, participating in the requested real image creation. Hence, nothing is changed when reducing to zero, the distance from one of the mirrors to the hologram i.e. when replacing the mirror by a reflecting layer deposited directly on the hologram surface. The same applies when the two mirrors are located outside the resonator or one of them plays the part of the end resonator mirror or when both of them play the part of the resonator boundaries with the active medium between them. The last case represents a reconstruction of the RIGLER type [5].

On the base of this analysis we suggest the use of the multiple-beam reconstruction in an indirect system i.e. with the auxiliary mirrors located outside the resonator cavity (Fig. 3) as there are some technological difficulties linked with the performance of the holographic mirrors. Even such a simplified version of the system should considerably improve the microsystem imaging and should, moreover, ameliorate the results of measurements obtained with the aid of the holographic interference and contouring methods.

The proposed method should also considerably ameliorate results of holographic laser microprocessing, in particular, when producing holes with the aid of holographic lenses [7].

3. Examination of the Semiconductor Laser Mode Distribution

The investigation of the radiation field distribution from a semiconductor laser in the near and the far range encounters some difficulties. These may be overcome by applying to semiconductor lasers the holographic technique used usually for the gaseous

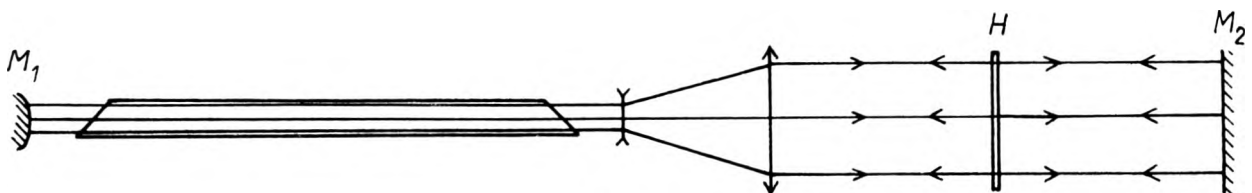


Fig.4a

the mirrors is to regain the zero-order beams and to employ them repeatedly in the reconstruction procedure. Because of some differences in phases appearing between the successive beams carrying the reconstructed image some sharpening of the energy distribution

and fluid lasers as well as for emission measurements of some radiation sources [8]. The photographic methods are useless to the measurements of this kind because of too small operating region of the photographic material characteristic used for intensity im-

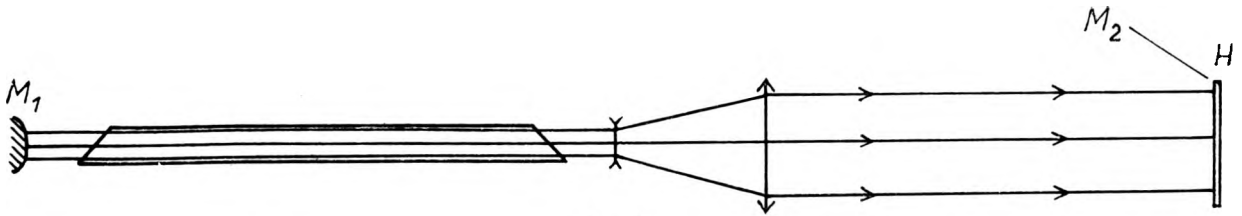


Fig. 4b

age registration. In spite of this the holograms — thanks to its property of recording the information about each object point accros the whole surface — render possibility of registering the images of intensity distribution much more differentiated such, for instance, which occur in the radiation field distributions of lasers operating in one transversal mode of high order or in the multi-mode regime. Since good photographic materials for close infrared are easily available the task seems to be relictically formulated. It is obvious that the method may also be used to examine uniform lighting of luminescence diodes.

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