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F. Arfelli, G. Barbiellini, P. Bregant, F. Calligaris, G. Cantatore, E. Castelli,
L. Dalla Palma, F. de Guarrini, R. Giacomich, R. Longo, P. Poropat, R. Rosei,
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R. Vidimari, F. Zanini, C. Zuiani.

SYNCHROTRON RADIATION FOR MEDICAL PHYSICS. A COMPARISON BETWEEN DIGITAL AND CONVENTIONAL SCREEN-FILM IMAGES

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SYnchrotron Radiation for MEdical Physics A comparison between digital and conventional screen-film images

F. Arfelli, G. Barbiellini, F. Calligaris, G. Cantatore, E. Castelli, R. Giacomich,
P. Poropat, R. Rosei, M. Sessa, F. Tomasini, A. Vacchi*
Dipartimento di Fisica dell' Università di Trieste
and
Sezione INFN di Trieste

L. Dalla Palma, R. Longo, F. Stacul , M. Tonutti, C. Zuiani
Istituto di Radiologia dell' Università di Trieste
and
USL - Trieste

P. Bregant F. de Guarrini, R. Vidimari
Servizio di Fisica Sanitaria, USL - Trieste

G. Tromba, F. Zanini
Società Sincrotrone Trieste

Abstract

A beamline devoted to mammography has been approved at the synchrotron radiation source Elettra under construction in Trieste, Italy. The SYRMEP (SYnchrotron Radiation for Medical Physics) program envisages the use of collimated, high intensity, tuneable, monochromatic X-ray beams from this source in conjunction with a new digital imaging system based on a silicon pixel detector.

In this paper we present a status report on this program. Experimental images are obtained, in the same illumination conditions, by means both of our new silicon detector and of a standard mammographic screen-film combination. The comparison of these images shows that it is possible to achieve, with our detector, a meaningful imaging capability, delivering a lower radiation dose than the one necessary when using conventional film, and with the ability to control image contrast.

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*) Società Sincrotrone Trieste.

Introduction

The SYRMEP collaboration is planning to use a beam of monochromatic X-rays, provided by the Elettra facility under construction in Trieste, in conjunction with a novel silicon detector to conduct research in digital mammography.

In a previous paper [1] we have reported on the results of the first tests of our detector prototype. Digital images of a lead mask exposed to a 40 keV X-ray point source placed in front of the detector were obtained using a laminar high efficiency silicon detector.

In the present paper we discuss images printed on conventional mammographic film using the same X-ray source and the same mask described in reference [1]. Further, we compare digital images from the silicon detector to the ones appearing on the film from the point of view of radiation dose. We conclude that the radiation dose required to obtain comparable images is much lower in the case of the silicon detector.

Materials and methods

Figure 1 shows a conceptual drawing of the apparatus used to produce digital images of a lead mask with a silicon detector and its associated electronics. This set-up is discussed in reference [1]. The images were obtained by illuminating a 500 µm thick lead mask, where the two letters "T" and "S" had been carved out, with an X-ray point source. This source consisted of a primary ^{241}Am gamma ray point source stimulating characteristic X-rays out of a metal target, the nature of which could be chosen among six different metals. A Tb target produced the 40 keV monochromatic X-ray beam. The mask, of area 25x30 mm^2, was positioned at a distance of 4.5 cm from the source and moved in front of the detector by means of a micrometer movement stage. At this distance the photon flux was 40 photons/s/mm^2. The detector sensitive surface was kept as close as possible (a few mm) to the mask. The detector proper consisted of a silicon strip detector manufactured by Hamamatsu Photonics K.K., Japan. A detailed description of this device can be found in reference [2]. For these measurements the total sensitive area was 7.5x0.5 mm^2. The complete image was composed by moving the mask in front of the detector in successive 500 mm steps.

The image of the mask on film was produced by directly exposing a standard film-screen mammographic imaging system (3M Mod. TRIMAX 100 NIF with KODAK MIN-R screen) at a distance of 4.5 cm from the X-ray source, which gave, using an Ag target, 22.1 KeV X-rays with a flux on the film plane of 20 photons/s/mm^2. The mask itself was set flat against the photographic plate holder. Some thermoluminescence dosimeters (Mod. GR-200 A produced by Nakajima) were placed on the mask at suitable positions in order to monitor the doses delivered in each exposure and the homogeneity of the illumination. This arrangement is schematically shown in Figure 2.

In order to understand the behaviour of the film at a very low photon flux, we compared the characteristic curves, which are plots of film optical density against the logarithm of the dose [3], obtained from high flux exposures performed using a commercial X-ray source for mammography (Mo anode at 17^0, filtration = 1mm Be + 0.06 mm Mo), to similar curves obtained from low flux exposures resulting from irradiation with our point source.

To measure the characteristic curves of our film, the film-screen assembly was placed at a distance of 65 cm from the focus of the X-ray tube. A 4 cm thick layer of perspex was placed in front of the X-ray beam to attenuate it. Different doses, monitored by dosimeters, were delivered to the film by selecting different "mAs" settings on the mammographic tube. The film, once developed, was scanned by means of a densitometer (X-Write, Mod. 331) to determine its maximum optical density. To exhibit a possible energy dependence of the characteristic curve we repeated the same measurements selecting three different voltage settings of the mammographic tube, at 22 kV, 25 kV and 30 kV.

A second set of optical density measurements was performed employing the same film-screen assembly positioned at a distance of 4.5 cm from the radioactive point source. Long exposure times were necessary due to the low activity of the source itself. In this case thermoluminescence dosimeters placed in the central portion of the film measured an integrated dose of 8.6 μGy in one hour.

Figure 3 shows the characteristic curves of the film obtained from the above measurements: optical density is plotted against total dose delivered to the film at different working voltages. The three sets of points representing high optical densities, and corresponding to exposures taken using a mammographic tube set at three different voltages, can be considered, for our purposes, to be overlapping. This means that, for a given total dose, the optical density of the exposed film is almost the same independent of the energy of the illuminating X-rays. The fourth set of data points plotted in Figure 3 represents optical density data obtained using the point source as an illuminator. Since the integrated doses delivered to the film by both the tube and the point source appear on the same scale, it can be concluded that at a lower photon flux the optical density is also lower even if the dose is the same.

This effect can be qualitatively understood in terms of a failure of the reciprocity law and of fading [4]. The reciprocity law states that the photographic effect depends on the product of the radiation flux and of the duration of the exposure and is independent of the rate at which the total dose is delivered. This law, however, fails for low photon fluxes. Fading of the latent image on the film occurs when there is a long time interval between exposure and development. Therefore, a film will not function properly at a low photon flux.

By inspecting Figure 3 one can see that an optical density of 0.35, for instance, corresponds to a dose of 40 μGy delivered by the mammographic tube in a short exposure time (typically 1 ms) and to a dose of 620 μGy delivered by the point source in a 72 hour exposure. Keeping in mind the above remarks on reciprocity and fading, one can conclude that, when comparing film images to digital images both obtained using the point source, an "effective dose" has to be considered. This effective dose can be estimated starting from the film optical density by means of the measured characteristic curves.

Results and discussion

Figure 4a and Figure 4b show digital images of the lead mask obtained using a silicon detector, after background subtraction, and with threshold discrimination, respectively. The total exposure time was 60 s and the corresponding dose was 0.15 μGy. This equivalent dose is calculated from dosimetric measurements carried out using the same point source and the same geometrical arrangement used to produce digital images. These images must be compared to the image shown in Figure 5, which appeared on film after development. In this case the exposure time was ~72 hours, i.e. 2.6×10^5 s, and the total integrated dose, as measured by means of dosimeters, was 620 μGy, corresponding to a maximum net optical density of 0.35. Such a high dose should produce film saturation (see Figure 3), however, according to the above discussion the effective dose to be taken into account is only 40 μGy. Finally, Figure 6 shows the image of the lead mask obtained by illuminating the film for about 1 ms with a mammographic tube set at 25 kV and 4 mAs, which are both normal settings used in the common diagnostic practice. The optical density is near saturation (≈ 1.2) and the total delivered dose is 300 μGy.

It is apparent from a visual inspection of Figures 4a-b and of Figure 5 that the quality of the images obtained is roughly comparable, while the delivered integrated dose is much different in the two cases. Digital images required a dose of 0.15 μGy to be produced; on the other hand a dose more than ~250 times higher was necessary to give an acceptable image on film. Further, a dose ~2000 times higher than 0.15 μGy has to be delivered to the film in order to obtain a standard quality image.

Conclusions

We have presented preliminary results of the comparison between two detection systems for X-ray mammography: a conventional film-screen assembly and the prototype of a silicon detector capable of producing digital images. The performance of the two detectors has been studied using a monochromatic X-ray radioactive point source and a lead mask as the phantom to be imaged.

We were able to obtain a digital image of good quality using the silicon detector while delivering to the phantom a total superficial dose of 0.15 μGy. Taking into account the film characteristic curves, which were also measured using a commercial mammographic X-ray tube, an equivalent dose of 40 μGy was necessary to produce an image of the same phantom on commercial mammographic film.

A second generation silicon detector, with a larger sensitive area and dedicated electronics, is at present undergoing testing in the I.N.F.N. laboratories in Trieste. With this device it will be possible to directly compare digital and film images of a standard phantom, simulating calcifications and nodules, using a mammography X-ray tube as a source of radiation.

Figure captions

Fig. 1	Experimental apparatus used to produce digital images by means of a silicon detector (see Reference [1]).
Fig. 2	Experimental set-up used to produce images by means of a conventional screen-film system (see text).
Fig. 3	Measured characteristic curves of commercial mammographic film (see text).
Fig. 4a	Digital image of a lead mask after background subtraction (see text).
Fig. 4b	Same image as in Figure 4a but with threshold discrimination.
Fig. 5	Image of the lead mask obtained by means of a conventional screen-film assembly using an X-ray radioactive point source.
Fig. 6	Image of the lead mask obtained by means of a conventional screen-film assembly using a commercial mammographic tube as an X-ray source.

References

[1] F.Arfelli et al., SYRMEP (SYnchrotron Radiation for MEdical Physics) - Performance of the Digital Detection System, presented to the VII Congresso Nazionale di Fisica Biomedica, Ancona, Italy (1992), INFN/TC - 92/18 (1992), accepted for publication on Physica Medica.

[2] G. Barbiellini et al., Solid state detectors for X-rays from Synchrotron Radiation, in Proceedings of the VI Congresso Nazionale A.I.F.B.,Genova, Italy (1991), "Topics on Biomedical Physics", L. Andreucci and A. Schenone eds., World Scientific (1992), p. 79.

[3] A.G. Haus, Sensitometric Techniques in Medical Imaging, in Collected papers from the 1979 American Association of Physicists in Medicine summer school, "The Physics of Imaging: Recording Systems Measurements and Techniques", A.G. Haus ed., Chapel Hill, NC, USA, 1979.

[4] F.H. Attix, Radiation Dosimetry, Vol.II, p. 332, Academic Press, New York (1966).

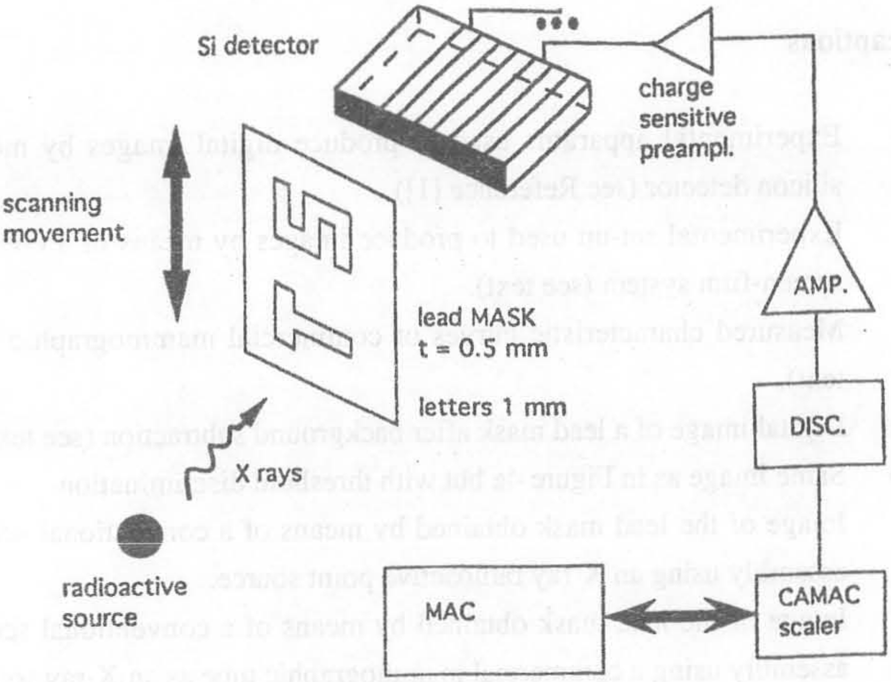

Si detector
charge
sensitive
preampl.
scanning
movement
AMP.
lead MASK
t = 0.5 mm
letters 1 mm
DISC.
X rays
radioactive
source
MAC
CAMAC
scaler

Fig. 1

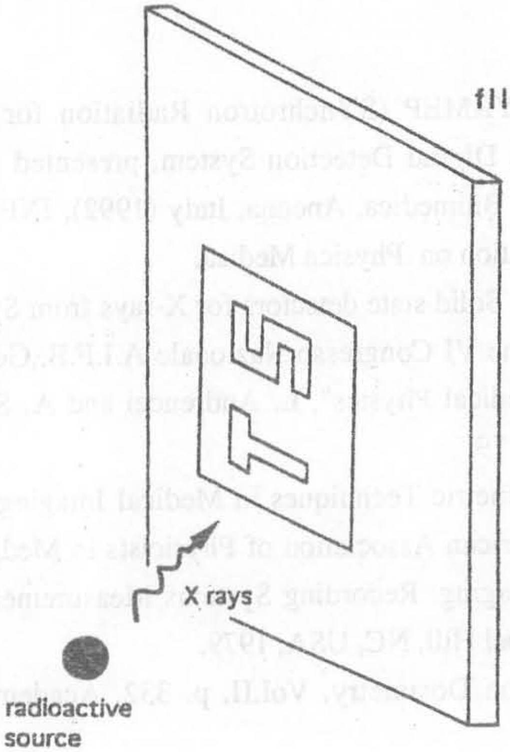
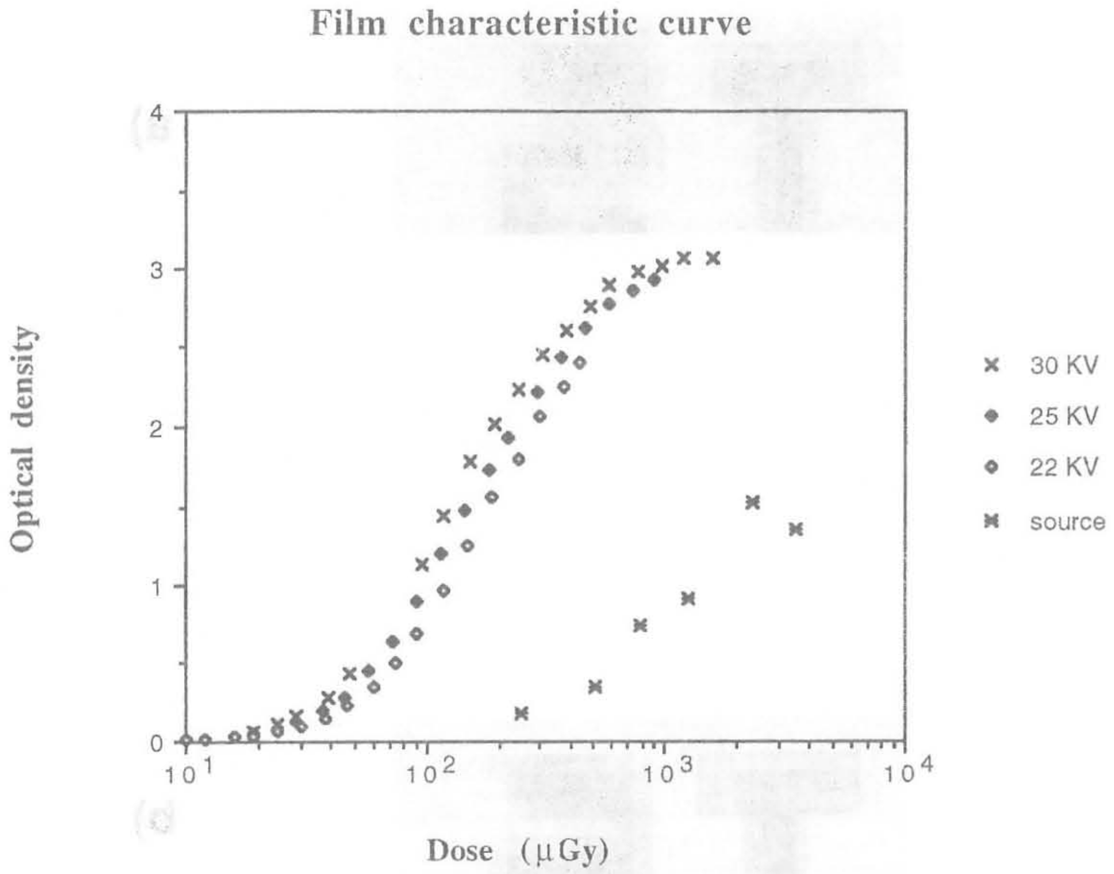

film
X rays
radioactive
source

Fig. 2



Film characteristic curve
Optical density
0
1
2
3
4
10^1
10^2
10^3
10^4
Dose (μGy)
× 30 KV
● 25 KV
○ 22 KV
✱ source

Fig. 3

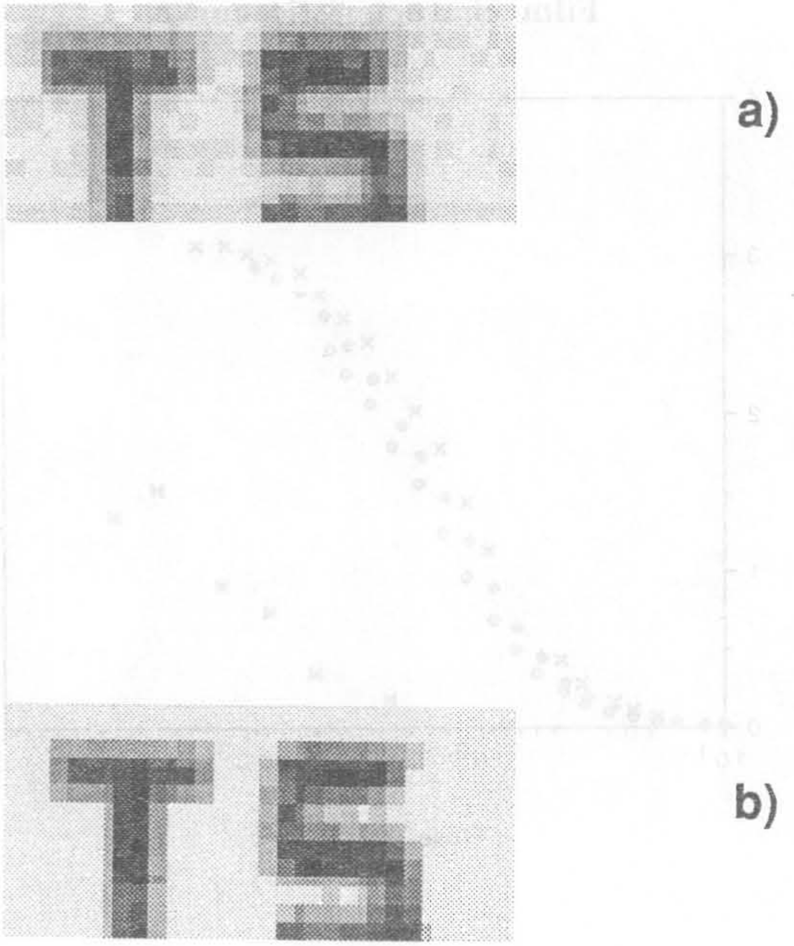


Fig.4

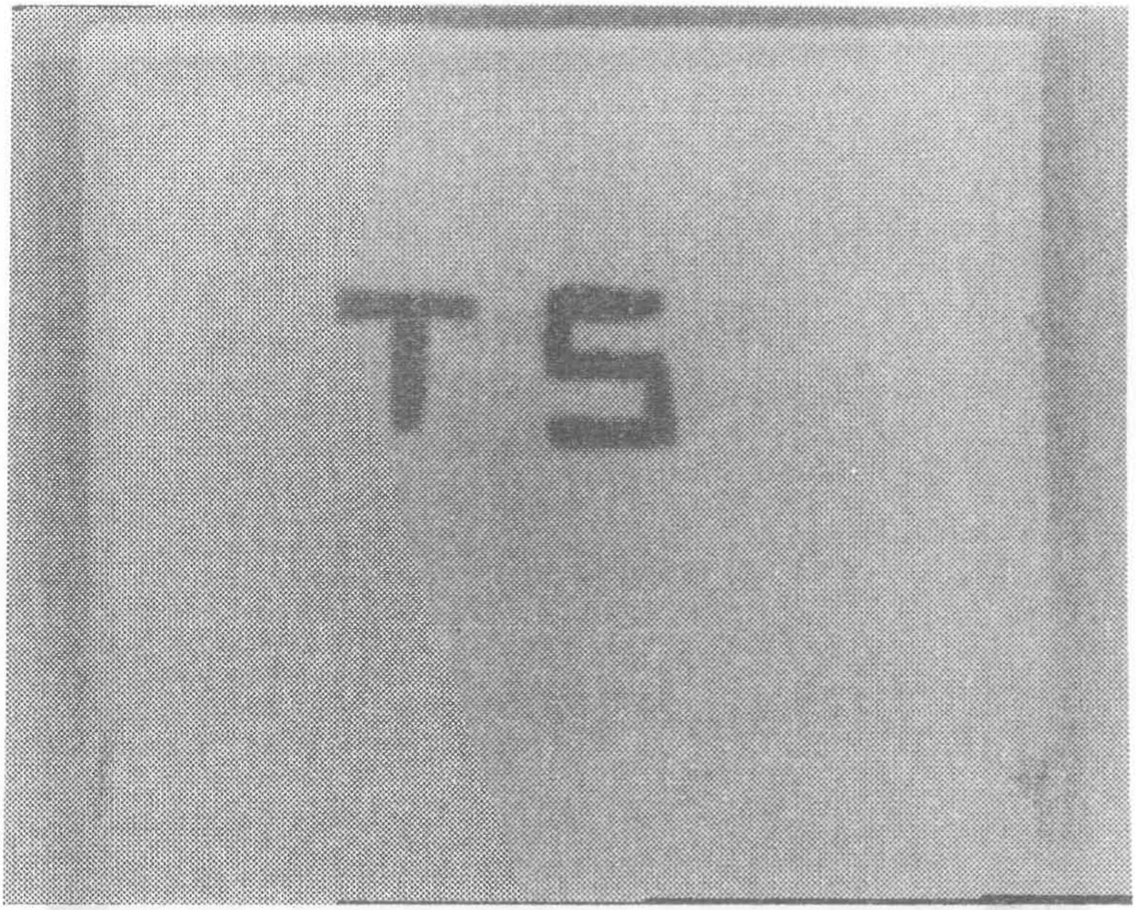


Fig. 5

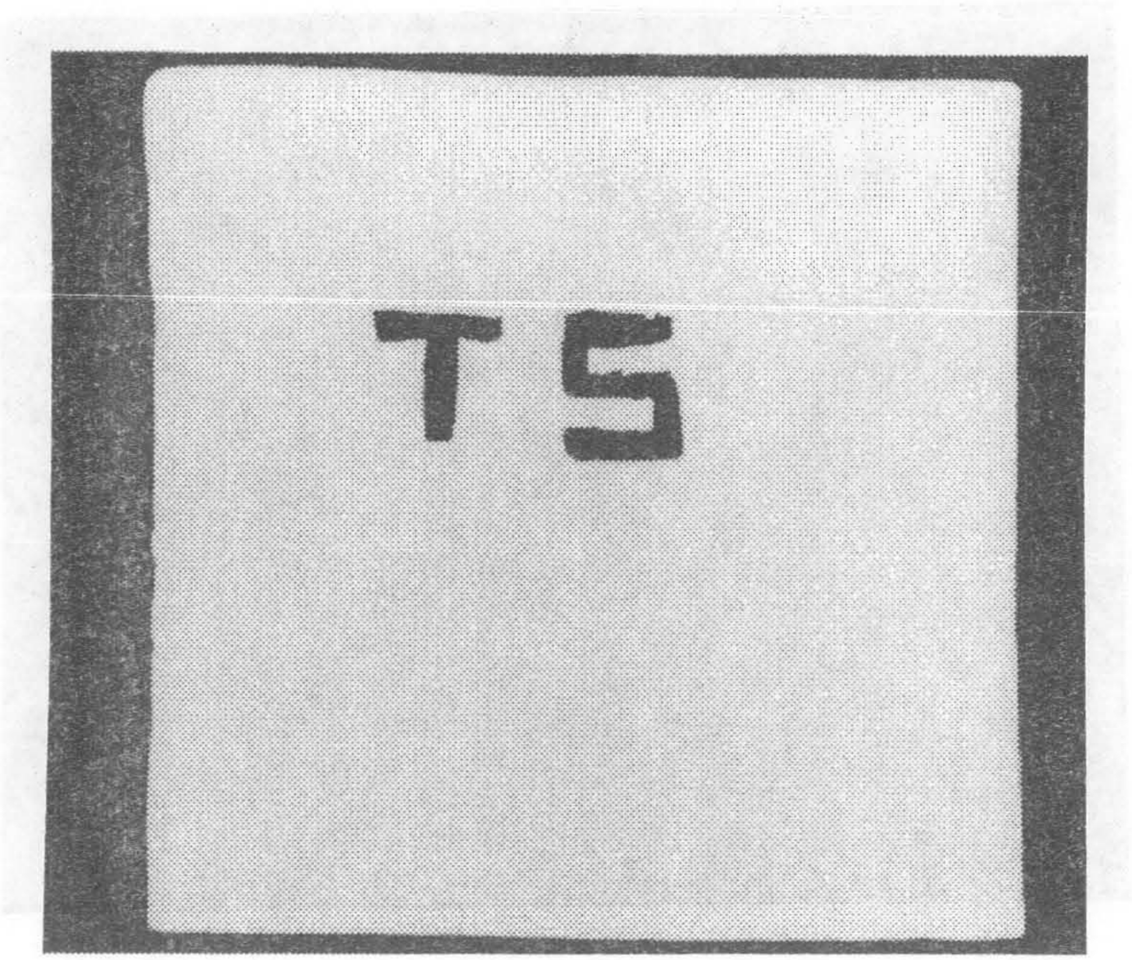


Fig. 6