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13. ABSTRACT ***(Maximum 200 Words)***
Collimated (parallel) beams can be used to remove scatter and improve resolution. Monochromatic x rays can be used to produce higher contrast images. Polycapillary x-ray optics technology can produce a highly parallel, monochromatic, x-ray beam from a conventional radiographic source.

Two prototype collimating optics were characterized. The one with the higher transmission was used for monochromatic imaging. The transmission for prototype II optic with a focal distance of 250 mm was ~ 37 % at 17.5 keV. The optic had good field uniformity and collected efficiently from a source up to ~ 0.7 mm in diameter. The divergence of collimation was only 3.9 ± 0.3 mrad. This shows the efficiency with which the beam can be monochromatized. These data were verified with computer simulations of ideal collimating optics.

The contrast results agreed with the theoretical calculations at 8 keV. The monochromatic values are on the average 5 times higher than the polychromatic case. At mammographic energies, 20 keV, the expected contrast enhancement is ~ 2.0 for 60 mm thick phantoms in addition to the contrast enhancement achieved from scatter reduction. The high contrast achievable with monochromatic parallel beam imaging has thus been demonstrated with a conventional source.

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Cisca Sugiro June 28, 2000

PI - Signature Date

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Introduction:

One in nine American women will develop breast cancer in her lifetime.[1] Screening mammography has proven to be the most effective procedure for identifying early breast cancers. Because early diagnosis is the key to reducing mortality, it is essential to provide the clearest possible image while minimizing the rate of false readings. Unfortunately, conventional mammographic techniques miss up to 10% of clinically obvious breast cancers[2] and also give a high fraction of false positive readings. Better x-ray imaging techniques are needed for mammographic screening. Our innovative imaging technique could have significant impact on the effectiveness of mammographic screening by providing dramatically better images. This new technique will incorporate an x-ray polycapillary optic followed by a single crystal to provide a highly parallel, monochromatic beam. Monochromatizing a conventional x-ray source will allow routine screening mammography to take advantage of high contrast, high resolution and reduced patient dose. These advantages have been demonstrated on expensive research tools such as synchrotrons and free electron lasers.[3, 4] Since the proposed technique creates the improved beam from a cheaper conventional x-ray source, this technique has enormous potential to become a highly effective tool for imaging carcinomas in a low-cost clinical environment.

Body:

Principle:

X-ray beams from conventional sources can be made highly parallel by using collimating x-ray polycapillary optics. The collimated beam is then monochromatized by diffraction from a single crystal. This highly parallel beam would virtually eliminate scattered radiation, with increased radiographic contrast.

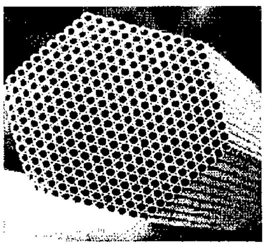

Figure 1. Cross sectional scanning electron picture of polycapillary fiber 500 μm in diameter. This fiber has approximately 100 channels, each 50 μm in diameter.

X-ray polycapillary optics are hollow glass capillary channels, usually made of borosilicate glass, fused together into a single fiber/bundle as shown in figure 1. These fibers are employed with channel sizes (5-50 μm) much smaller than the outer diameter (300-1000 μm). X-rays striking on the interior of these channels at grazing incidence are guided down through the channel by total external reflection in a process similar to how fiber optics guide light.[9,13] The critical angle (θ_c) for total external reflection from borosilicate glass is 1.5 mrad (0.09°) at 20 keV, and is inversely proportional to x-ray energy.

Thousands of fibers are laced through aligned metal grids to from a pre-patient collimating optic (see figure 2). These optics are readily available as commercial products in sizes to 16 cm^2.

Characterization:

Two collimating optics have been characterized: prototype I has been designed for 8 keV and prototype II for 20 keV. Table 1 lists their parameters. For characterizing these optics, a copper rotating anode and a NaI detector were used.

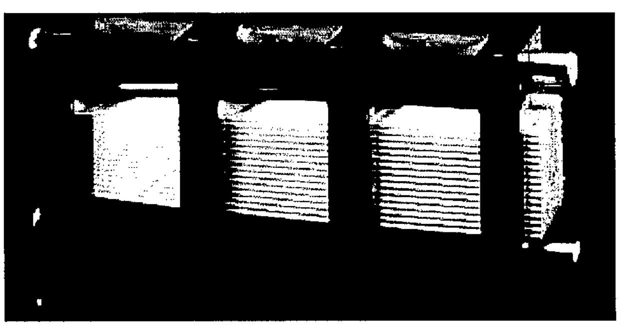

Figure 2. Multi-fiber collimating optic. Output is 20x20 mm, length is 10 cm.

The transmission as a function of source-optic distance is plotted for focal distance determination in the respective cases for the two optics in figure 3. At the focal distance, the transmission is the highest. For prototype I, it is about 6 % and for prototype II, it is about 39 %. The depth of field is the range of the source-optic distances for which the transmission is unchanged. This is shown clearly in figure 3; for prototype I the depth of field is only 3 mm, while prototype II has 10 mm depth of field.

Table 1: Prototype Optics Comparison

Parameters	Prototype I	Prototype II
Length	105 mm	127 mm
Field Shape	Circular	Square
Input Diameter	23 mm	8.07 mm
Output Diameter	30 mm	10 mm
Focal Distance	150 mm	250 mm
Acceptance angle	9 °	1.8 °
Fiber Outer Diameter	510 μm	510 μm
Fiber Channel Diameter	12 μm	10 μm

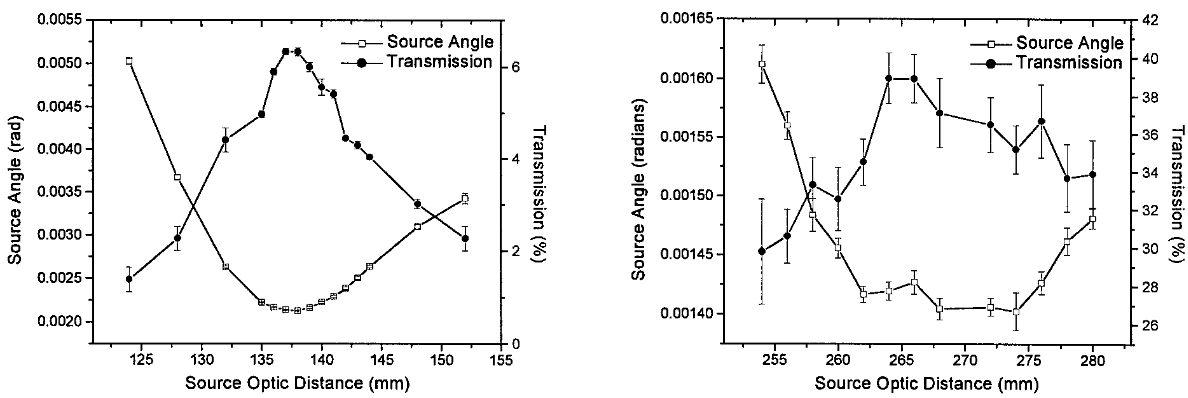

Figure 3: Both transmission and source angle are plotted as a function of source-optic distance for prototype I (left) and II (right).

Figure 4 shows the transmission as a function of source offset for each of these optics. The width shows how large a source can be seen by the optic. The smallest width occurs at the focal distance of the optic. Note that the width of the scan for prototype II does not change significantly between the three distances due to the large depth of field.

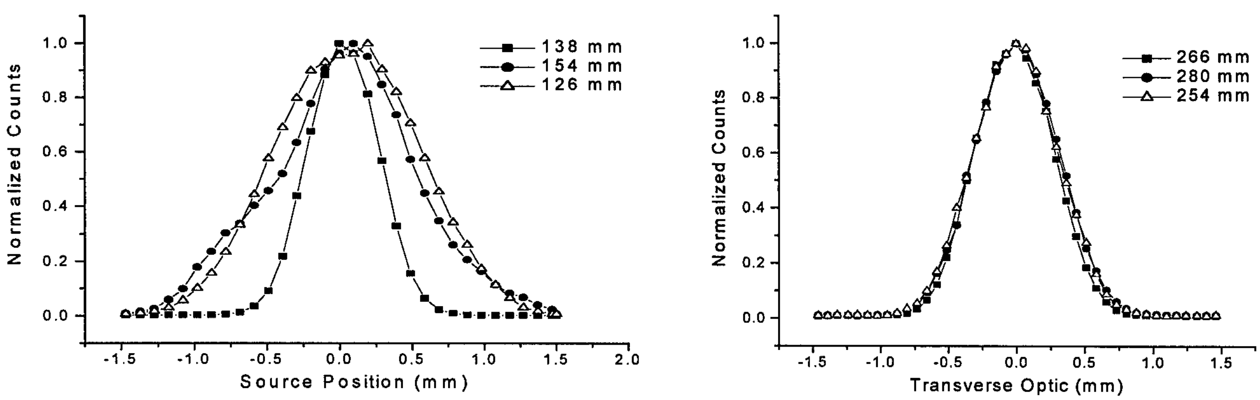

Figure 4. Source scans for prototype I and II optics. The FWHM's are 0.57 ± 0.003 mm and 0.68 ±0.005 mm respectively.

Transmission uniformity, shown in figure 5, was performed with a molybdenum source and a germanium detector for prototype II at molybdenum K α line 2 keV detector window.

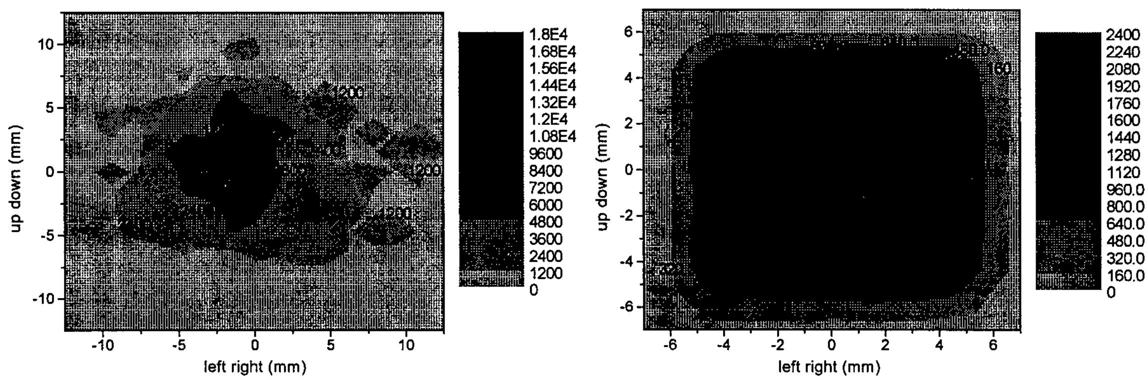

Figure 5. Transmission uniformity for prototype I and II. The uniformity is 40 % 4.5 mm by 4.5 mm square for prototype I and only 3 % for prototype II

Since prototype II has a better transmission and uniformity, transmission was measured as a function of energy with a molybdenum source and germanium detector. The data was simulated with both X-ray Optical Systems propriety code for an ideal collimating optic and our Center for X-ray Optics code which includes the effect of both waviness and bending. Waviness is a parameter, that describes the random tilt of the glass surface. The waviness was determined to be $\phi = 0.15$ mrad and the bending of the central "straight fiber to be given by a radius of curvature R = 125 m.

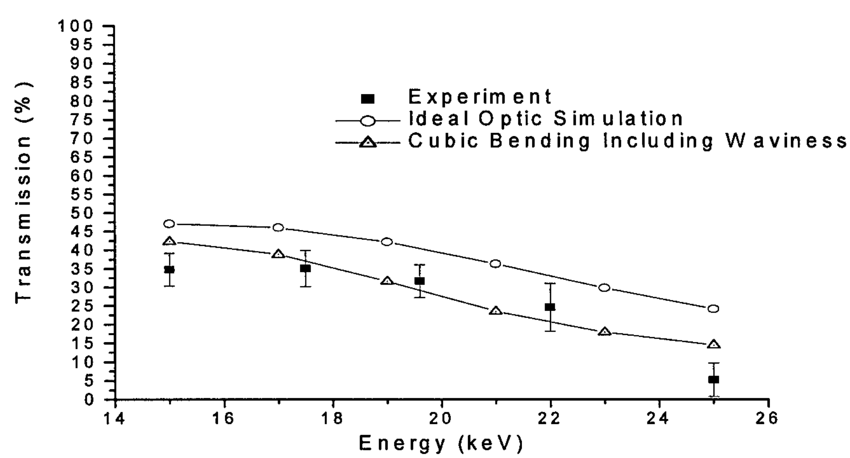

Figure 6. Experimental and simulation comparison

Divergence was measured with a silicon wafer rocked in the output beam. The experimental set-up is shown in figure 7.

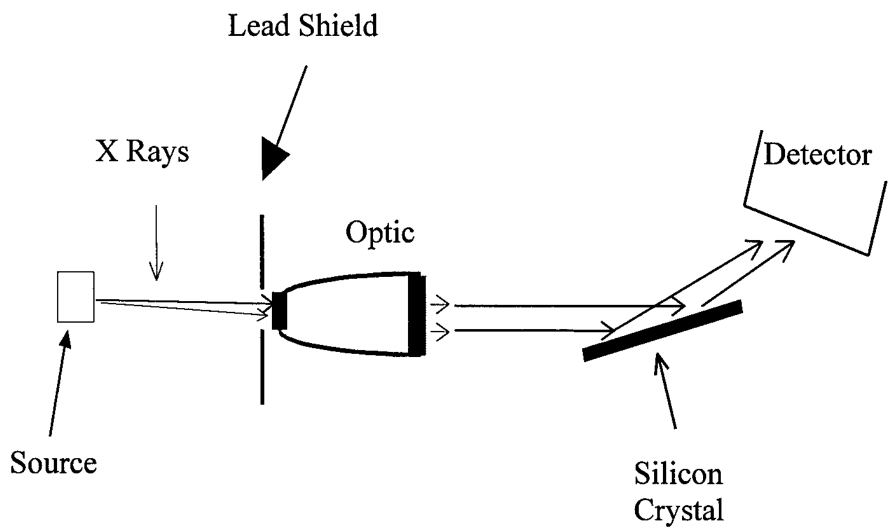

Figure 7. Experimental set-up for divergence measurements

The FWHM for the rocking curve at K_β (8.9 keV) is 3.9 ± 0.3 mrad. Divergence uniformity has not yet been measured.

The simulation is on-going. A visual basic code for output divergence is being created for collimating lenses.

Monochromatic Imaging

Monochromatic imaging has been performed with polypropylene plastic phantoms at 8 keV. The measurements were performed at 8 keV initially because that was the most intense source available. The designs of the phantoms are shown in figure 8. Fuji plate images obtained behind the optic (polychromatic) with behind the optic/crystal combination (monochromatic) are compared in figure 9.

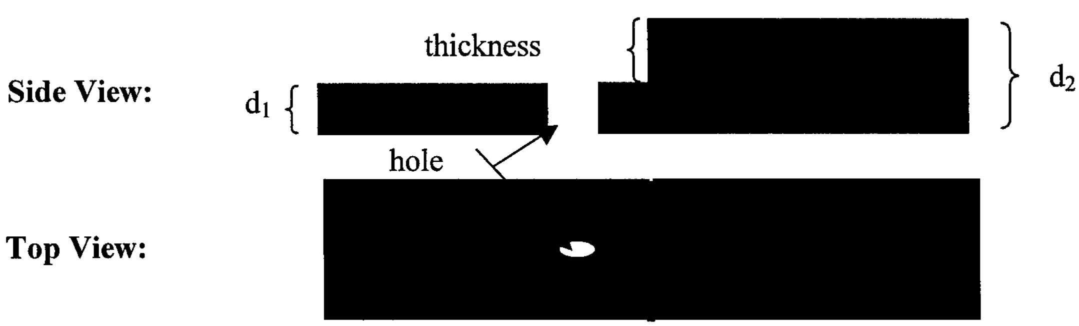

Figure 8. Polypropylene plastic phantom construction used for contrast enhancement experiments

The contrast enhancement for monochromatic images is 5 times than for polychromatic ones. Table 2 summarizes the contrast results for each thickness and a sample of Fuji image is shown in figure 9.

The total photon flux is about 700 photons per second at the copper K_{α} line. The beam uniformity is not yet performed, but the Fuji plate images show a pretty uniform output beam image. Resolution measurements are still inconclusive because of suspected x-ray fluorescence from the iron razor blade sharp edge. The scatter fraction is less than one percent for both cases.

Table 2: Contrast Comparison

Thickness (mm):	**Experimental Polychromatic:**	**Theoretical Polychromatic:**	**Experimental Monochromatic:**	**Theoretical Monochromatic:**	**Experimental Ratio:**	**Theoretical Ratio:**
1.5	0.2 ± 0.1	0.2	0.6 ± 0.2	0.6	3.0 ± 2.0	3.0
2.0	0.4 ± 0.2	0.2	0.7 ± 0.2	0.7	2.0 ± 1.6	3.5
4.0	0.5 ± 0.2	0.3	2.2 ± 0.3	1.4	4.0 ± 2.1	4.7
7.5	0.8 ± 0.2	0.7	4.2 ± 0.3	2.6	5.5 ± 2.0	3.7
15.5	1.1 ± 0.3	1.2	5.3 ± 0.4	5.2	4.8 ± 1.6	4.4

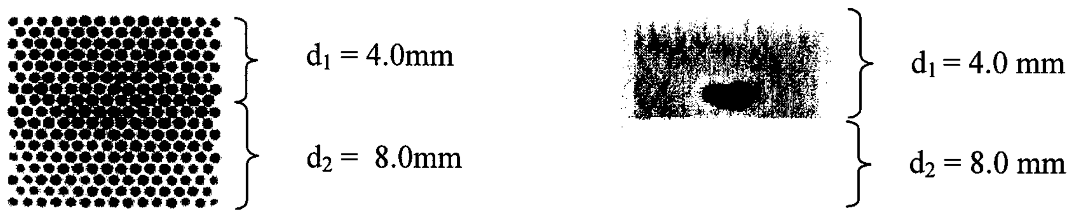

Figure 9. Sample of Fuji plate image. Left is the polychromatic case while the right is the monochromatic one.

1) Key Research Accomplishments:

• Transmission with a prototype II optic is ~ 39 % with the rotating anode and a NaI detector

• The focal distance of the prototype II optic is ~260 mm with the rotating anode and a NaI detector

• The uniformity of the prototype II optic is 3 % for a 4.5 mm by 4.5 mm square field

• The divergence of the prototype II optic is 3.9 ± 0.3 mrad at the copper K_β line.

• Monochromatic imaging shows a 5 times contrast improvement than polychromatic imaging at 8 keV. Theoretically, a contrast enhancement of two is calculated at 20 keV.

2) Reportable outcomes:

None

Conclusion:

To date, results have been promising with prototype optic II, which has a high transmission of about 39 %. It has been clearly shown that the contrast is significantly better in the monochromatic case than the polychromatic case. The exposure with the Fuji plate is only 30 seconds (300mA seconds) with a conventional copper rotating anode source. Thus, it has been proven that monochromatic mammography can be done with cheap conventional source for clinical setting. Patient dose will be low because only monochromatic beam reaches the patient.

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[1]Wood, Sylvia. (1998, June 16). "Dispelling Myths about Mammography," Times Union, p. D4.

[2]Baker, L. H. "Breast Cancer Detection Demonstration Project: Five-year Summary Report CA." 32, 194-225, 1982.

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