Finding Nearly Perfect Diamonds to Use in Probing the Atomic Nucleus

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If I Had a Diamond

A diamond wafer is useful for producing an x-ray beam.

When a beam of high-energy electrons passes through a diamond wafer, it loses energy in the form of x-rays, or photons. These x-rays can be used to look deep inside the core of an atom, just as you can probe a bag of marbles by poking your finger into it.

If we use a nearly perfect diamond, we'll get a high-quality x-ray beam. Owing to the regularity of the crystal structure, our x-ray beam will be in phase and have a single wavelength, just like a laser. This allows us to see as clearly as possible into the atomic nucleus.

Synthetic Diamonds

Natural diamonds, we discovered, would not produce an x-ray beam that met the stringent standards of the upcoming GlueX experiment.

What do you do when diamond just isn't good enough? Use sythetic diamond. Over the past few years, Drukkers, a daughter company of DeBeers, has been developing a process to manufacture diamond of a quality even higher than natural diamond by depositing carbon vapor at high temperature and pressure. Through a colleague at the University of Glasgow, we obtained several samples of this prototype synthetic diamond. To determine if they were of sufficiently high quality, we subjected these samples to tests at the Synchroton Radiation Source in Daresbury, England.

Our tests, undertaken in collaboration with Drukkers, were the first of their kind for synthetic diamond.

Diamond's Structure

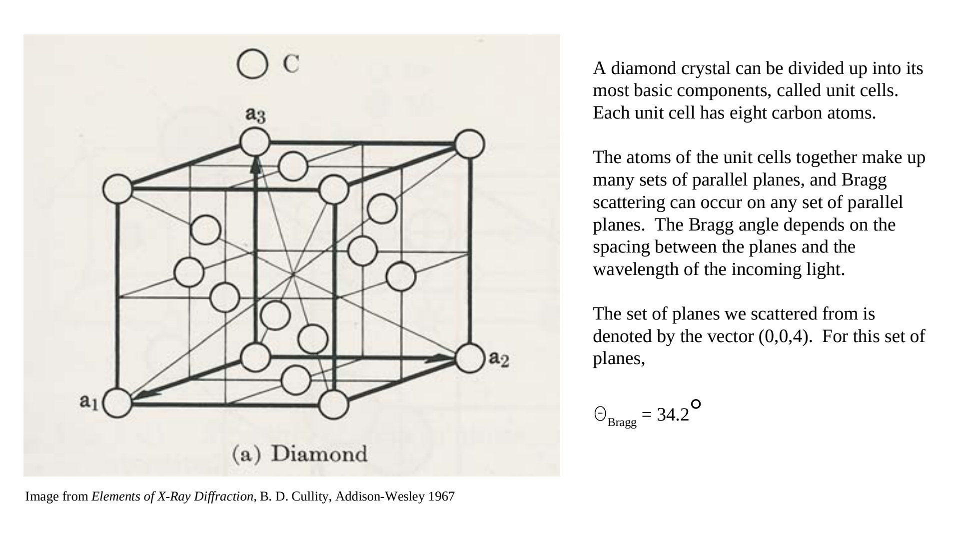


Image from *Elements of X-Ray Diffraction*, B. D. Cullity, Addison-Wesley 1967

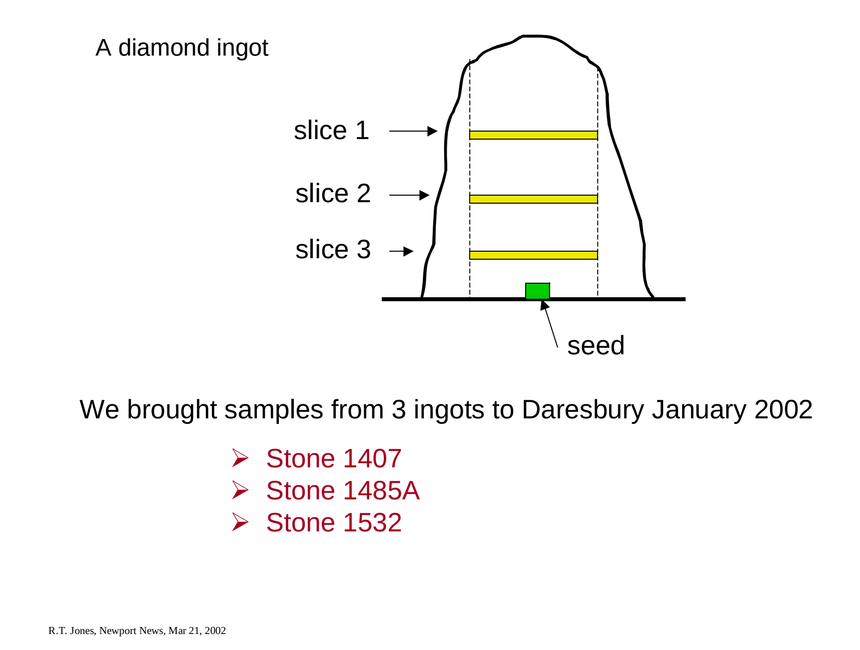
A diamond crystal can be divided up into its most basic components, called unit cells. Each unit cell has eight carbon atoms.

The atoms of the unit cells together make up many sets of parallel planes, and Bragg scattering can occur on any set of parallel planes. The Bragg angle depends on the spacing between the planes and the wavelength of the incoming light.

The set of planes we scattered from is denoted by the vector (0,0,4). For this set of planes,

$\Theta_{Bragg} = 34.2^{\circ}$

Synthetic Diamond Samples

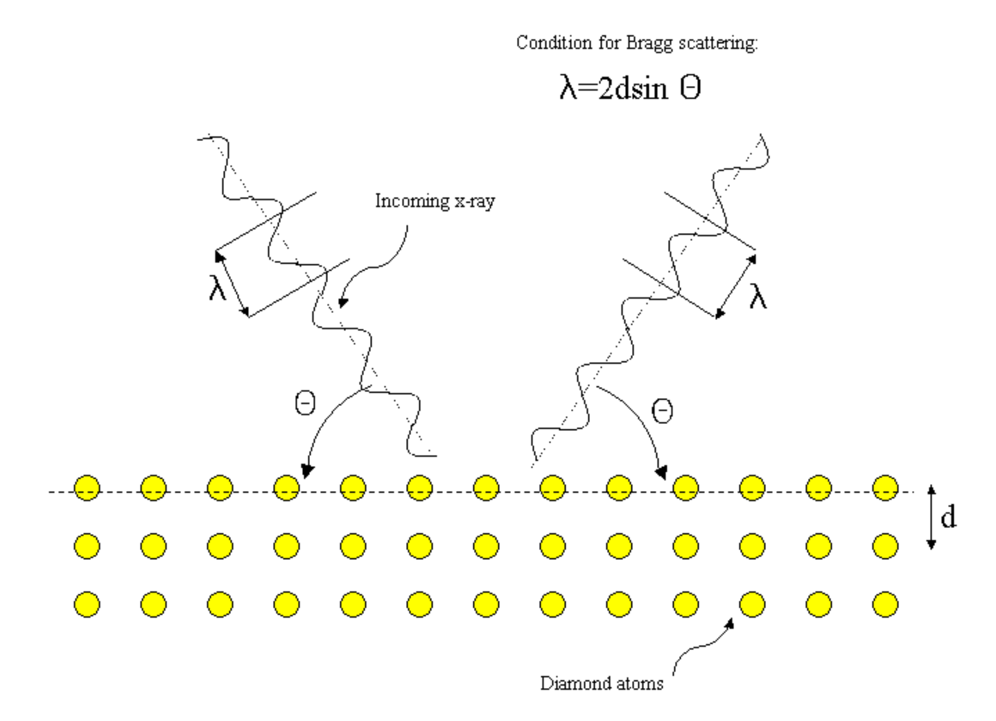


We brought samples from 3 ingots to Daresbury January 2002

- Stone 1407
- Stone 1485A
- Stone 1532

R.T. Jones, Newport News, Mar 21, 2002

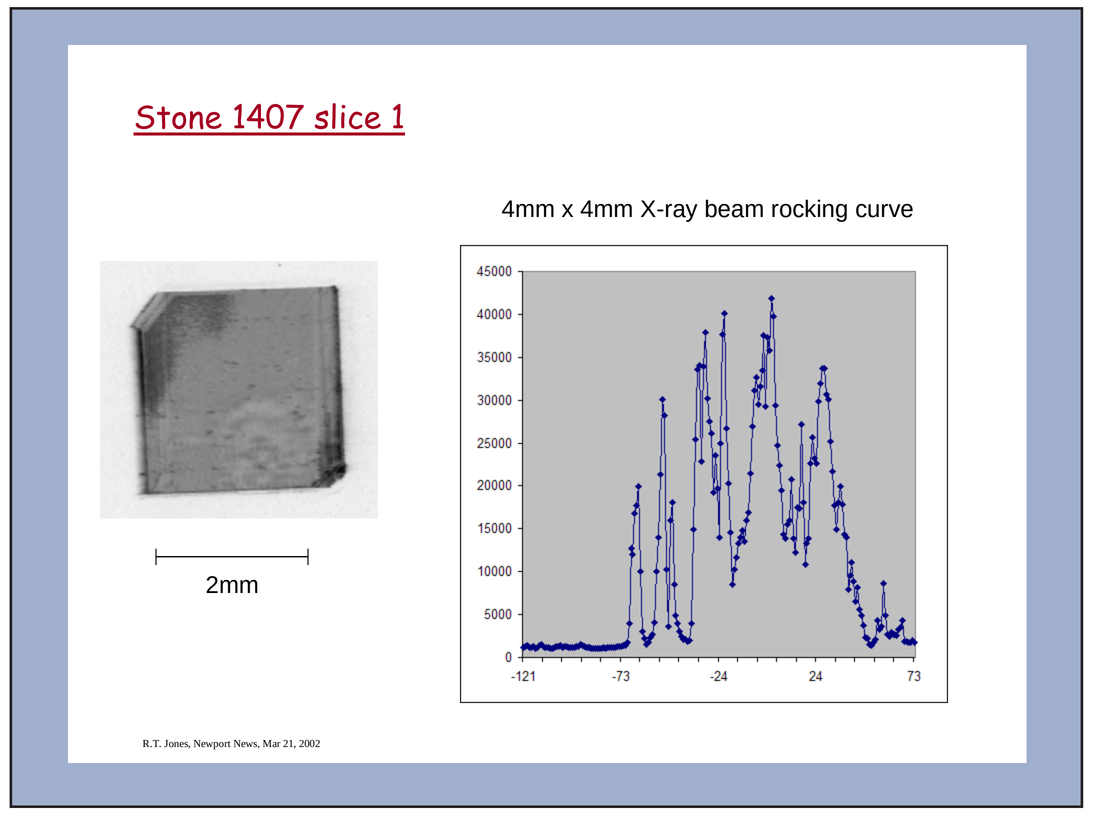
Bragg Scattering



Condition for Bragg scattering:

$\lambda = 2d\sin\Theta$

A Bad Crystal



Stone 1407 slice 1

4mm x 4mm X-ray beam rocking curve

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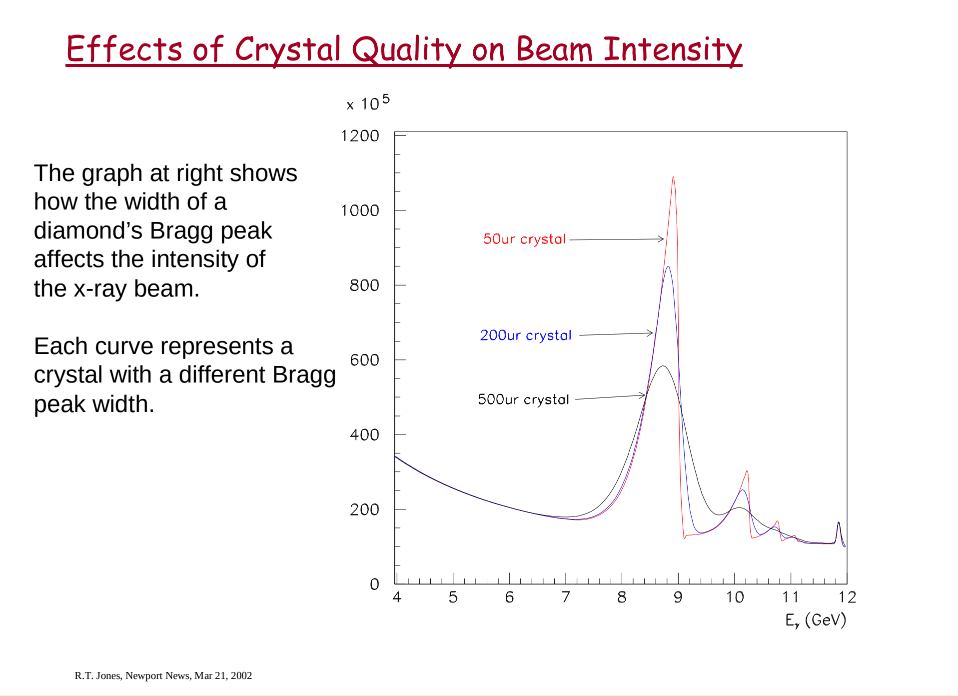
How Good Is Good Enough?



Effects of Crystal Quality on Beam Intensity

The graph at right shows how the width of a diamond's Bragg peak affects the intensity of the x-ray beam.

Each curve represents a crystal with a different Bragg peak width.

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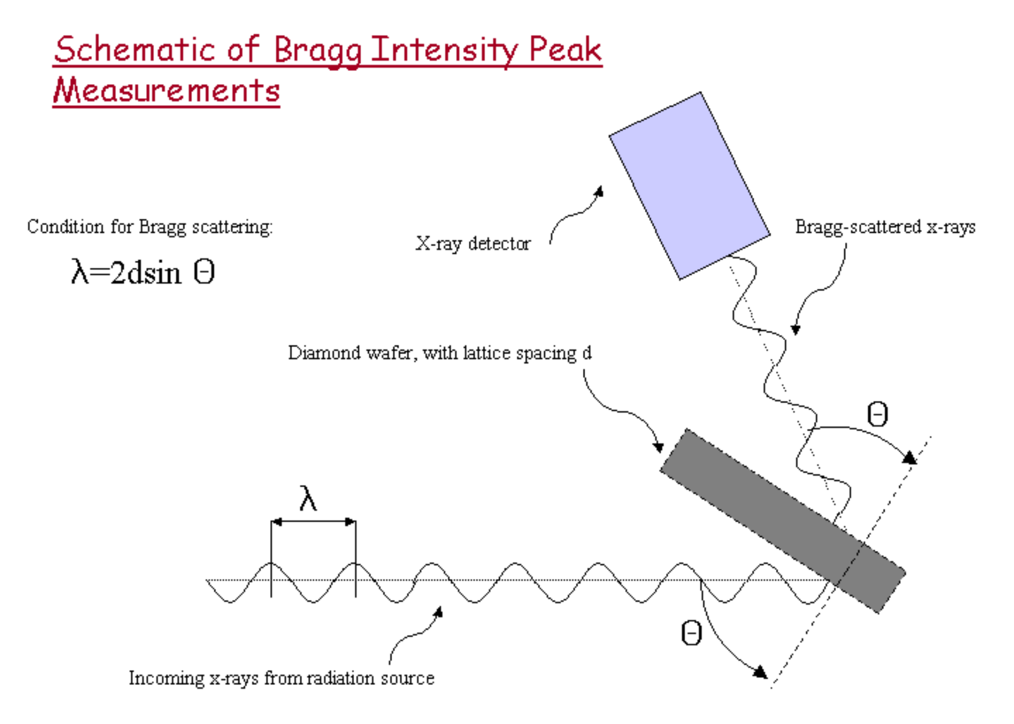
Bragg Peak Measurements

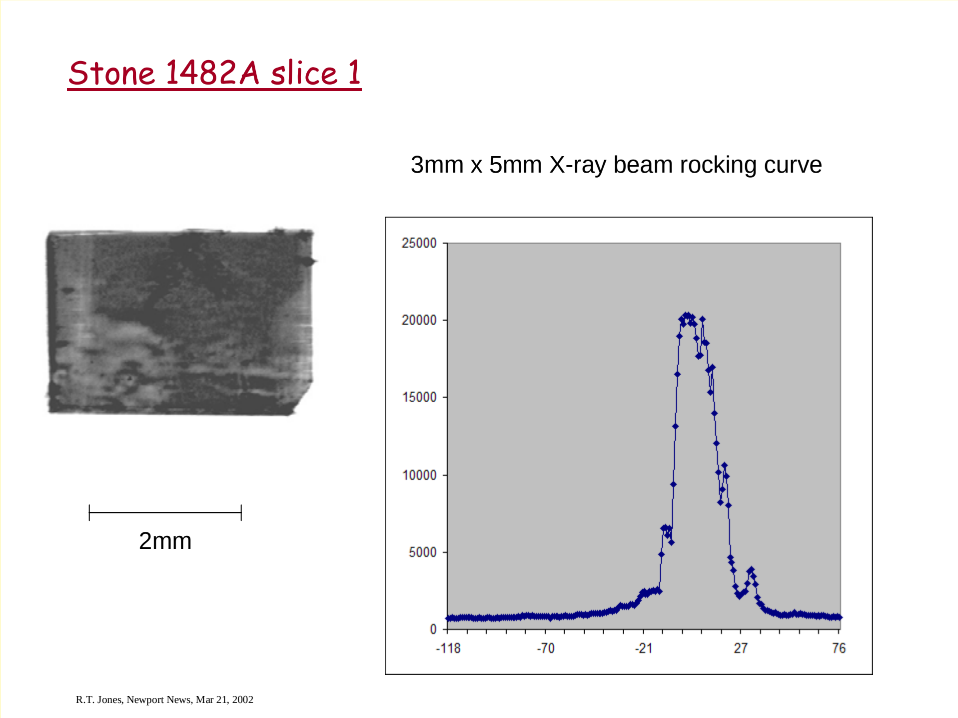


Schematic of Bragg Intensity Peak Measurements

Condition for Bragg scattering:

$\lambda = 2d\sin\Theta$

A Good Crystal



Stone 1482A slice 1

3mm x 5mm X-ray beam rocking curve

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Examination of Samples

At the Synchrotron Radiation Source in Daresbury, England, we scattered x-rays from the synthetic diamond samples. We looked at the x-rays scattered at the Bragg angle, where there is a high intensity of reflected x-rays because reflections from the crystal's many planes interfere constructively.

First, we exposed photographic plates at the diamonds' Bragg angles. Patterns of dark and light in these photographs indicate stresses in the crystal, whereas a uniform exposure indicates a crystal with few stresses.

Next, we moved the crystals slowly through their Bragg angles and measured the intensity of the scattered x-rays as a function of angle. A narrow Bragg peak indicates a crystal with a regular lattice structure, but a wide and irregular peak indicates imperfections in the crystal.

Conclusion

We demonstrated the availability of high-quality synthetic diamonds suitable for use as x-ray radiators in the GlueX experiment. Of our six samples, one (stone 1482A, slice 1) was well within the design specifications for GlueX.

We also discovered that examining the Bragg peaks of candidate radiators is completely necessary. Although x-ray topographs give some information about the crystals, they were not a good predictor of the width of the Bragg peak. The technique of examining Bragg peaks with x-ray scattering, however, proved sufficient to distinguish the good crystals from the bad ones.

In collaboration with industry and the University of Glasgow, we expect to be able to provide suitable diamond radiators for the GlueX expeiment -- nearly perfect diamonds.

Collaborators:

Richard Jones, University of Connecticut

Jim Kellie, University of Glasgow

Ranko Vrcelj, University of Southampton