Practical 1P7: Bubble Raft

What you should learn from this practical

Science

You should be able to recognise a variety of point defects, edge dislocations and grain boundaries in the bubble raft. The existence of a dislocation will be established by measuring a closure failure in a Burgers circuit in the raft. The structures of grain boundaries will be seen to depend on the misorientation between the adjoining rafts.

When the raft is disturbed by tilting or shaking the tray slightly you should see dislocations moving and interacting with each other, with grain boundaries and with point defects. You will see the planes on which slip occurs (i.e. the lines along which the dislocations move) within a grain.

Finally, you will model recovery and recrystallisation by stirring up the raft with a glass rod and then letting it heal over time.

Practical skills

You will photograph your observations. For this it is recommended that you use your own devices (e.g. smartphone); make the demonstrators aware if your group does not have access to a digital camera in some form. Optionally, you may also find it helpful to record videos of the raft to capture the movement defects etc.

Safety Considerations

Be careful that you do not slip on any spilled water or detergent; if you group spills any fluid then wipe it up immediately and warn others to avoid the spillage.

Note that the detergent used in this experiment is very strong – students with sensitive skin should take suitable precautions.

<u>If your group is asked to create glass tubes:</u> Take care when drawing down glass tubes with a flame. Beware of the glass and the flame, and be conscious of the people around you. You must wear a lab coat, gauntlets and safety glasses. Scrap glass must be put in the broken glass disposal box.

Introduction

A bubble raft is a raft of bubbles on the surface of a liquid. When the raft is made carefully, so that the bubbles are small and have the same size, it forms an excellent two dimensional model of a crystalline metal. The regular hexagonal arrangement of the bubbles is analogous to the regular structure of a close packed plane of atoms in a metal like aluminium or copper. That in itself is not very interesting. What makes the bubble raft so useful is that the **defects** in the regular hexagonal array of bubbles are closely analogous to many of the defects in a real crystalline metal. This analogy was recognised in the middle of the last century when W L Bragg and J F Nye published a paper in the Proceedings of the Royal Society (Series A, **190**, 474 (1947)) showing photographs of defects in bubble rafts. Perhaps they got the idea from staring at the bubble raft on the surface of a pint of beer, or on the surface of a soapy bath. Wherever the idea originated from it has helped generations of materials scientists to get a picture of what defects in metals look like. In fact the bubble raft does more than that because one can use it to see how defects interact with each other, how they move and how they can be destroyed. Thus, the bubble raft provides a picture of the dynamical behaviour of defects as well as their structures when they are stationary.

But, be warned that the 2-dimensional nature of the bubble raft imposes quite severe limitations on it as a representation of a real metal, which is clearly 3-dimensional. For example, an important class of dislocations, called screw dislocations, cannot exist in a two-dimensional bubble raft; in fact all the dislocations one sees in the bubble raft can only be pure edge dislocations.

Overview of practical

You will be shown an excellent film about the Bubble Raft made by Bragg. You will then produce your own bubble rafts; you made need to make your own glass tubes for this purpose, or they may be supplied. You will take photographs of point defects, dislocations and grain boundaries. You will then disturb the raft to study the motion of defects, their interactions and their annihilation. Finally you will study the evolution of the bubble raft after giving it a good stir to observe the recovery and recrystallisation. You will take a series of photographs, and optionally videos, throughout the practical in order to record your observations. Throughout the practical you will describe your observations in your lab notebook. ***You should select the photographs that you have taken which best capture each of the phenomena that you were able to see, and then print the photographs so that you can include them in your lab book – make sure to include a clear caption for each one.***

If you wish to include a video as part of your documentation of the experiment, then you can ask a demonstrator how to upload the file – typically it will be to a location on the Canvas system.

Experimental details

1. If your group has been asked to make fine glass tube nozzles: Make these by heating glass tubes and stretching them rapidly outside the flame. However suitable tubes may be provided. If indeed you do make tubes, briefly describe the process in your lab notebook.

2. Pour soap solution into a tray, with the black plate on the bottom of the tray to help you see and photograph the bubbles that you will grow. Pour slowly to avoid many unwanted bubbles. Attach the glass tube to the rubber tubing from the nitrogen cylinder. Adjust the flow from the cylinder carefully so that a sensible rate of bubbles is produced in the liquid when the fine nozzle is placed in the tray. Blow the bubbles away from the nozzle as they are produced to prevent them from stacking up in clumps. It will take 15-30 minutes to grow a good bubble raft, covering most of the tray. If your bubbles are larger than 2 mm make another nozzle. Describe the key elements of this process in

your lab notebook, including any extra ‘tricks’ you found to make it work. Estimate the typical size of a single bubble in a ‘good’ patch of bubble raft – note the size estimate, and how you made the estimate, in your lab notebook.

3. You will see that the raft consists of patches in which the hexagonal arrangement of bubbles has a constant orientation, but which changes between different patches. These patches are the analogues of individual crystals or ‘grains’ in a polycrystal, and the line where different patches meet is a grain boundary[1]. Within each patch you should see a hexagonal arrangement of bubbles, within which you can identify 3 families of lines at 60º to each other along which bubbles touch (these lines are called close-packed directions). The close-packed directions are equivalent to crystal axes and they define the orientation of each grain. Their orientation changes abruptly at a grain boundary. The angle through which the close-packed directions change across a grain boundary is called the misorientation. The maximum possible misorientation is 30º between different grains in the bubble raft. The misorientation is one of the characteristics of a grain boundary. The other is the line in the bubble raft along which the boundary exists (this is the analogue of the boundary plane in a three-dimensional metal). **Take pictures of different grain boundaries and select one**

[1] Remember that because the raft is 2-dimensional, a defect that is planar in a 3-dimensional metal, such as a surface or a grain boundary, becomes a line in the bubble raft, and a linear defect, such as a dislocation, becomes a point in the bubble raft. Exceptionally, a point defect is just a point in both the 3-D metal and the bubble raft.

or two to print for your lab book, identifying the misorientation and the line along which the boundary exists. Comment in the lab notebook on whether you see any semblance of structural order in your grain boundaries, or would you describe them as having random structures. If you have understood WHY the maximum misorientation is 30º then note the reason in your lab notebook, using a sketch if you wish.

4. Within each grain you should see a relatively perfect hexagonal array of bubbles, with occasional point defects. **Find and photograph examples of the following point defects, and include printouts with captions in your lab notebook:**
    a) a substitutional impurity (a bubble that has a different size from the rest, occupying a site of the hexagonal lattice).
    b) a vacancy (a missing bubble).
    c) an interstitial (a bubble occupying a site that is not on the hexagonal lattice, but which is squeezed in between the bubbles of the hexagonal array).
    d) You may be lucky and be able to observe more exotic combinations of point defects, such as di-vacancies (two vacant sites next to each other), or Frenkel defects (an interstitial and a vacancy near to each other). Photograph any such interesting cases. But make sure you do not mistake a dislocation for a point defect. One quick and easy way to distinguish them is to tilt the tray of the bubble raft gently. If the defect moves it is very likely to be a dislocation.

A longer, but more rigorous, way of establishing whether the defect is a dislocation is to construct a Burgers circuit. This is treated next.

5. If you tilt the tray gently or otherwise stress the raft you will see defects moving rapidly along the close-packed directions within each grain. These defects are dislocations. Locate one of these defects near the centre of a grain. If you look along the close packed rows you should see that the dislocation is located at the point where a close-packed row of bubbles terminates. **Photograph this dislocation for your lab book***.* Look along the other close-packed rows and describe what you see. Notice the extra 'half-plane' of this edge dislocation.

   What is the direction of the dislocation 'line' with respect to the bubble raft? You will now investigate this using the Burgers circuit, which is a construction that not only tells you whether the defect is really a dislocation, but also characterises the dislocation in terms of a vector called a Burgers vector. **Do the following using a photo of a dislocation, or a sketch of the photo if it is difficult to annotate the photo.** Choose a bubble a few away from the defect that you believe is a dislocation. Call this bubble ***A***. Perform a right-handed (clockwise) circuit, starting and ending at ***A***, around the dislocation by counting along the close-packed rows. It is crucial that your circuit encloses the dislocation. For example, you might have to go 6 bubbles to the right, 5 downwards, 5 to the left and

5 upwards to end up at ***A*** again. If you now repeat this circuit in a perfect region of the raft (elsewhere in the photo, or even in another photo), by counting out the same numbers of bubbles to the right, down, to the left and up, you will find that the circuit will not end at the same bubble at which you started. This closure failure is the signature of a dislocation: if you have a point defect, such as a vacancy, there will be no closure failure. The closure failure of the circuit (which is called the reference circuit) in the perfect crystal is called the Burgers vector. In fact we haven't defined the positive or negative sense of the vector uniquely yet. To do that we need a convention. It doesn't matter which convention we choose so long as we stick to it for all dislocations. For a Right- Handed circuit around the dislocation line the Burgers vector points from the Finish to the Start: the FS/RH convention. **Following this procedure, you should now have sketch and/or photos in your lab notebook, that show the construction of Burgers circuit around the dislocation that you recorded. In your notebook, show both the magnitude and the direction of the Burgers vector.**
In your notebook, describe how the direction that defects move (when tilting the raft) relates to the Burgers vector.

Extra info: The two parts of the raft on either side of the close-packed row of bubbles, along which the dislocation moves, undergo a relative displacement equal to the Burgers vector. For this reason the Burgers vector is sometimes called the slip vector: it is the vector by which the two regions of crystal slip past each other when the dislocation moves. In 3-dimensions the dislocation line moves along a plane and that plane is called the slip plane. The Burgers vector, or slip vector, is the relative displacement of the two parts of the crystal on either side of the slip plane. In the bubble raft the slip 'plane' is just the close-packed row of bubbles along which the dislocation moves.

6. Now perform the following investigation and describe your observations in your lab notebook.
   Tilt or shake the tray gently to move dislocations. **What happens when dislocations reach the edge of the raft, or a grain boundary?** If you are fortunate you will see dislocations meeting each other - **what happens? Do dislocations interact with point defects, such as vacancies, interstitials and substitutional point defects in the raft? If so, how?** Try to **photograph** as many of these phenomena as you can. If you wish you also make a video of this activity, and upload it to a suitable location (speak to a demonstrator to hear the upload location) – if you do this, refer to the video in your lab notebook and state what phenomenon is captured in the video. In any case, make sure to **describe** your observations and **sketch what happens**.

7. Do the following and describe the results: Stir the bubble raft gently with a glass rod. This creates a high density of defects in the bubble raft, which is analogous to a piece of metal that has been deformed at low temperatures ('cold-working'). Observe, record and photograph what happens in a period up to 20

minutes after you have stopped stirring. You should see that many of the defects you introduced by stirring are gradually removed[2], and that the grain size increases. This is the analogue of recovery and recrystallisation. Be warned that many of the changes take place very rapidly in the first 10 seconds or so after you stop stirring, and then the changes occur much more slowly.

Rough Timetable

Day 1: Watch the film by Bragg. Obtain your glass nozzle, and grow your bubble raft. Photograph stationary grain boundaries, point defects and dislocations. Study the dynamical interactions between defects by disturbing the tray gently, using photography and optionally video to record it. Stir the raft to simulate recovery and recrystallisation.

Day 2: If you did not complete the tasks to your satisfaction, you may return on the second day to finish them.

What should be in the lab notebook

You have already received advice on how to properly document a series of experiments in your lab book. The only unusual feature of this experiment is that it is important to document the phenomena you observe using photographs. These will be taken by, e.g., your phone

[2] With the exception of vacancies, which are formed by bubbles popping. Obviously there is no analogue to this phenomenon in a real metal!

and printed using the local printer. You may wish to trim and glue photographs into the lab book, or you may wish to include entire printed pages of photos – but in either case make sure that it each photograph has an accompanying description in the lab book and that the link between the description and the corresponding photograph is clear (e.g. number them).

It is also appropriate to include sketches in your lab book when you wish to describe something that is not easy to capture with a photograph.