27-750
Texture, Microstructure & Anisotropy
formally known as
Advanced Characterization and Microstructural Analysis

Spring Semester 2016
Last revised: 30ᵗʰ March, 2016

Course Description
The purpose of *Texture, Microstructure & Anisotropy* is to acquaint the student with a selected set of characterization tools relevant to the quantification of microstructure (including crystallographic orientation, i.e. texture) and anisotropic properties. The motivation for the course is problem solving in the areas of property measurement (e.g. grain boundary energy), prediction of microstructural evolution (e.g. in grain growth and recrystallization), and prediction of properties based on measured microstructure (e.g. anisotropy of work hardening and ductility). The specific objectives are to develop skills and understanding in the following areas:
(1) The mathematical basis for crystallographic orientation and grain boundary distributions, with explanations of the many representations of rotations/orientations;
(2) Crystallographic preferred orientation (texture) and its representation by pole figures, inverse pole figures and orientation distributions, with a particular emphasis on the effects of symmetry in representations;
(3) Texture of interfaces and its representation by misorientation distributions and Grain Boundary Character Distributions (or Interface Character Distributions in the case of poly-phase materials);
(4) Methods of measuring texture such as X-ray diffraction and Electron Back Scatter Diffraction (EBSD) with reference to orientation mapping (OIM); brief introduction to high energy diffraction microscopy (HEDM);
(5) The effect of texture on elastic and plastic anisotropy in polycrystals; the uniform stress model (Sachs), the Taylor-Bishop & Hill model, the Eshelby analysis;
(6) Image analysis and extraction of 3D information using stereology. This is applied in particular to the analysis of grain boundaries (see #3 above);
(7) Phase transformations and Orientation Relationships.

Emphasis is placed on the use and understanding of quantitative tools for texture data acquisition & analysis (e.g. orientation distribution determination from pole figure data, and automated electron back-scatter diffraction/EBSD/OIM), the effect of crystal and sample symmetry on distributions and their representation, and the prediction of anisotropy (e.g. calculation of yield surfaces for plastic deformation). Since the datasets are often large, such as from EBSD scans, computer programs are essential. Note that the current title of this course is "Texture, Microstructure & Anisotropy" because of the emphasis on these aspects of anisotropic microstructure-property relationships.

4 hours lecture per week (12 units in the CMU system).

Class Schedule.   This is a 12 unit class for graduates Spring, 2016, and meets twice a week for a total of 4 hours, 11:30-1:20, Tuesday and Thursday in Porter A7F (changed from Wean 5201). The lectures will be given by Prof. Anthony Rollett (CMU). Since there will be other participating institutions (e.g. GaTech), each lecture will be made available as a Powerpoint file at the following website shortly before the class begins: pajarito.materials.cmu.edu/rollett/27750/27750.html. The lectures will be available via bluejeans (videoconferencing software) and the links to the recordings will be posted weekly. See the end of this document for a schedule, with adjustments for absence of the instructor. A likely time slot for make-up lectures is 2-4 on Thursdays.

Recommended Pre-requisites: 27-201 (Structure of Materials), 27-202 (Defects in Materials), 27-301(Microstructure and Properties I). The course requires students to be comfortable with (or develop skills in) basic aspects of crystallography, crystal plasticity and the mathematics associated with geometry, vectors, tensors and rotations.

Textbook: Kocks, U. F., C. Tomé, and H.-R. Wenk, Eds. (1998). *Texture and Anisotropy*, Cambridge University Press, Cambridge, UK, ISBN 0-521-79420-X. This is now available as a paperback. An additional book that is very useful because of its coverage of electron back scatter diffraction is *Texture Analysis: Macrotexture, Microtexture & Orientation Mapping*, by Val Randle and Olaf Engler (2000), Gordon & Breach, Amsterdam, Holland, ISBN 90-5699-224-4. A book with considerable mathematical detail on texture is Adam Morawiec's *Orientations and Rotations* (2003), Springer, ISBN 3-540-40734-0.

Topics Covered
1. Microstructural Characterization Techniques with Orientation
   - Average texture by X-ray diffraction pole figures
   - Electron diffraction in the SEM (EBSD, OIM); analysis of EBSD data acquisition
   - Serial sectioning for 3D mapping
   - 3D Orientation mapping with synchrotron radiation
2. Analysis of Characterization data
   - Basics of Image Analysis
   - Stereology (selected examples)
   - Interface networks, dihedral angles
   - Serial sectioning (e.g. alignment of parallel sections)
   - Percolation Analysis (e.g. for electrical conductivity)
   - Shape and Cluster Analysis (e.g. of particles)
   - Reconstruction techniques 3D for digital microstructures
   - Boundary tangent analysis to obtain 5-parameter distributions
3. Representation of Texture
   - Mathematical Representations of Orientation
   - Crystal, Sample Symmetry
   - Graphical Representations of Texture
   - Orientation Distributions
   - Interface texture – misorientation (3-parameter) vs. boundary normals (5-parameter)

- Lattice Curvatures (geometrically necessary dislocations)
4. Analysis of Orientation Distributions (OD)
   - OD calculation from projections (pole figures)
   - Analysis of OD data for volume fractions
5. Interfaces
   - Characteristics and properties of grain boundaries
   - Coincident Lattice Site theory
   - Calculation of Misorientation Distributions (MDs) from EBSD data
   - Analysis of MD data
   - Texture derived MD (TMD); normalization of measured MDs by TMDs
6. Structure-Property Relationships
   - Anisotropy of second rank tensor properties, e.g. conductivity
   - Anisotropy of fourth rank tensor properties, e.g. linear elasticity
   - Anisotropy of non-linear tensor properties, e.g. plasticity; Taylor-Bishop-Hill theory for crystal plasticity; yield surfaces
   - Eshelby analysis (inclusions, effective medium theory)
7. Microstructural Evolution
   - Grain growth
   - Recrystallization
   - Texture development via plastic deformation

Course Objectives and Relationship to Program Objectives (Target Skills)
The motivation for this course is that many practical problems in materials science (and solid state physics) have to do with polycrystals and the fact that they behave differently depending on what direction is tested; this is known as *anisotropy*. Whether it is the anisotropy of elastic modulus, yield strength, strain ratio, magnetizability, permeability, or electrical properties, the methods used to quantify the anisotropy are the same. Although the field of texture & anisotropy has grown up as a separate subdiscipline, it is actually part of the broader topic of microstructure-property relationships. There is also a close relationship to materials processing because the texture of a material is dependent on its history. The common use of Electron Back-Scatter Diffraction (in the scanning electron microscope) or EBSD has played a major role in bringing texture and microstructure together.

The formal goal of the course therefore is to instruct students to advanced concepts of microstructural characterization. These include stereology, topology, and texture and methods of measuring microstructure including crystallographic orientation. In addition, the impact of microstructure on the directionality of materials behavior is discussed with respect to mechanical behavior. For MSE undergraduates (at CMU) taking the course, it has the most impact on Outcome A, development of a knowledge of mathematics, physics, chemistry, materials and statistics to identify, formulate and solve the problems encountered in the production or application of a material. The discussion of anisotropy addresses Outcome G, development of an ability to employ the techniques, skills and tools of modern engineering practice in materials engineering. Through classroom interaction and presentation of projects and/or homeworks, communication skills are

developed (Outcome C). The examples of application of quantitative microstructural techniques addresses both the design of systems (Outcome E) and the application of core concepts in materials science (Outcome B).

Contribution to meeting the professional component (undergraduates).   27-550 is primarily intended to introduce students to the concepts required to quantify microstructure, including texture (crystallographic preferred orientation) and to connect microstructure to the elastic and plastic behavior of engineering materials. Practical examples of the impact of anisotropy based on microstructure are introduced to motivate the discussion, e.g. earring in beverage cans, directionality in the electrical properties of superconductors.

Course Assistants. The course assistant for grading of homeworks etc. is TBD.

Prepared by: Prof. Anthony D. Rollett. The instructor can be reached in his office, Wean 3313, by phone, 412-268-3177, or by email, rollett@cmu.edu. An open door policy applies but feel free to email in order to obtain a definite time to meet.

Lecture Schedule

Lecturers: A.D. (Tony) Rollett *[ADR]* at CMU

Timetable of Lectures

Lectures take place in Wean 5201 on Tuesdays and Thursdays and runs from 11:30am to 13:20.

CMU Semester starts Jan. 11th. First class on Jan. 12th.

Week 1

Jan. 12th	*[ADR]*	Introduction to Microstructure, including texture (crystallographic orientation): examples of engineering problems involving texture; What is a Texture Component? Miller indices and Euler angles; orientation as rotation; stereographic projections; Pole Figures (L1).
Jan. 14th	*[ADR]*	Texture Components and Euler Angles: part 1. Show how to convert from a description of a crystal orientation based on Miller indices to matrices to Euler angles. Give examples of standard named components and their associated Euler angles. The overall aim is to be able to describe a texture component by a single point (in some set of coordinates such as Euler angles) instead of needing to draw the crystal embedded in a reference frame. Part 1 provides a mainly qualitative, pictorial approach to illustrate the physical meaning of Euler angles and "orientations". Texture Components and Euler Angles:

Homework 1: exercises on locating components, conversion from one representation to another.

Week 2

Jan. 19th	*[ADR]*	Texture Components and Euler Angles: part 2 provides more mathematical detail, e.g. mathematics of conversion from Miller indices to a rotation matrix to Euler angles.
Jan. 21st	*[ADR]*	Symmetry; Sample vs. Crystal Symmetry; Effect of symmetry on Representation of Texture; square, polar plots; invariant measure.
Jan. 22nd	*[ADR]*	*Dept. Seminar by ADR will count as an EXTRA LECTURE*

Homework 2:

Week 3

Jan. 26th	*[ADR]*	Pole Figures, Stereographic Projection, Equal Area Projection (L4).
Jan. 28th	*[ADR]*	[Double lecture] *First lecture*: Orientation Distribution; Orientation space; OD maps; Euler angles; discrete vs. functional ODs; Texture Components (L5). *Second lecture*: Volume fractions; Misorientation calculation (L6).

Week 4

Feb. 2th	*[ADR]*	Calculation of Orientation Distributions from Pole Figures; harmonic method, WIMV method.
Feb. 4th	*[ADR]*	Tour of MTEX; students need to have a copy of Matlab installed and working. Example of analysis of a set of pole figure data measured for a sample of low carbon steel to obtain an orientation distribution (function), using the MTEX software package. This will be a hands-on demonstration with opportunities for students to demonstrate their own use of the package. The accompanying homework will require students to use the package to generate a "standard set" of plots and other analyses. Students will be required to refine the defocusing and background corrections in order to optimize the solution (L9).

Week 5
Feb. 9th   *[ADR]*   EBSD data acquisition, esp. Hough transform (L8).

Feb. 11th   *[RMS]*   Guest lecture by Prof. *R.M. Suter* (Physics) on High Energy Diffraction
                           Microscopy (HEDM)
[Instructor absent on Feb. 11th]

Week 6

Feb. 16th   *[ADR]*   [Instructor absent for TMS meeting]; no lecture
Feb. 18th   *[ADR]*   Elastic anisotropy (L9);
Feb. 19th   *[ADR]*   *Revision session, time TBD.* Come prepared with questions. Instructor will
                           review the topics covered thus far.

1st Test will be take-home; release date is Sat., Feb. 20th, due 11:59 Sun., Feb. 21st.

Week 7
Feb. 23rd   *[ADR]*   (L10) *Plastic Anisotropy*: Single Crystal Plastic Anisotropy: Schmid's Law:
                           Rate Sensitive Yield.
Feb. 25th   *[ADR]*   (L11) *Plastic Anisotropy*: Introduction to the Taylor model; The Bishop-Hill
                           model. Taylor Model for anisotropy.

Week 8
Mar. 1st   *[ADR]*   Short presentations (10 mins.) on a topic relevant to 27-750 by students (but it is
                           strongly suggested that the topic is the same as for the term paper). 1st group:
                           Chen, Cunningham, Feng, Fu, Harrison, Hsu, Mangal. Remaining time will be
                           used to answer questions, cover topics not discussed fully in previous classes.
Time, name
Mar. 3rd   *[ADR]*   Short presentations, 2nd group: Cohn, Tang, Toman, Wang, Zhong

Since these presentations will be graded, only students taking the class for credit will be required to give
presentations. Note that we will continue the discussion of the Taylor Model in these sessions once the
presentations are completed.

(Spring Break starts Mar. 7th)
Homework: solution of Bishop-Hill equations for single crystals (use of matlab required)

Week 9
Mar. 15th   *[ADR]*   (L12) *Plastic Anisotropy*: r-value, single crystal and polycrystal yield surfaces.
Mar. 15th   *[ADR]*   [extra lecture, Tues @ 2] (L13) Grain Boundaries, Misorientation Distributions,
                           Fundamental Zone for MD, plotting of MD.

Mar. 17th   *[ADR]*   (L14) Grain Boundary Engineering; what is a Coincident Site Lattice? CSL
                           boundaries.

Homework:

Week 10
Mar. 22nd   *[ADR]*   (L15) Stereological approach to 5-parameter grain boundary character
                           distributions.
Mar. 24th   *[ADR]*   (L16) Stereology

Week 11

Mar. 29th   *[ADR]*   No class [Instructor absent]

Mar. 31st   *[ADR]*   Mar. 31st*[ADR]*   (L17) EBSD Analysis

Week 12
Apr. 5th   *[ADR]*   @4:30p.m.! (L18) Grain boundary properties; GB Energy.

Apr. 7th   *[ADR]*   (L19) Grain Growth, Normal.

Week 13
Apr. 12th   *[ADR]*   (L20) Rodrigues vectors, quaternions, rotation matrices, useful math [Tugce
                           Ozturk, under the Future Faculty program]
Apr. 14th   *[ADR]*   No class (Carnival)

Week 14
Apr. 19th   *[ADR]*   (L21) Grain Growth, Abnormal
                           [Instructor will lecture via videoconf.]
Apr. 21st   *[ADR]*   (L22) Texture development in thermomechanical processing
Review session @ 4pm

Homework:
Second Test is a take-home, as before, April 23rd and 24th

Week 15   Last Week of Classes at CMU:
Apr. 26th   *[ADR]*   (L23) Statistics of grain size distributions (from Dr. S. Donegan)
Apr. 28th   *[ADR]*   (L24) Orientations and Phase Transformations (from Dr. B. Anglin)

The written report that is the complement to the presentation is due Tuesday, May. 3rd. This will be configured as a "Turnitin" assignment. No presentation (beyond the one given in February) is required.

Unassigned lectures:
Unassigned homeworks:

Homework: application of popLA to a data set provided by the instructors; practice with popLA to analyze a data set with iteration on the defocusing correction; maps of components in various spaces; analysis of students' samples' pole figure data with popLA; conversions of sets of discrete data to intensities in orientation space; calculation of locations in pole figures from texture component locations in orientation space.

Homework: literature search; stereology, topology questions
Homework: calculation of OD's from measured textures
Homework: Stereology, image analysis, use of ImageJ
Homework: texture development in thermomechanical processing
Homework: calculation of percolation of a network; pair correlation function.
Homework: Triple Junctions, equilibrium at junctions, networks of boundaries.
Conversions between different grain boundary descriptions.
Stereology
Topology of Microstructures
Grain Growth

Calculation of volume fractions along the beta fiber in rolled Cu (Hwk 3 from Spg 2000).

Measurement of a set of PF data (each student will provide their own specimen)

Test, Exams, Grading Policy

Homeworks: approx. 1 per week   100 points

Exams: one in-class test at mid-term; one open book test near the end of the course - see weighting below

Grading Policy   A > 90%
                                  B > 80%
                                  C > 65%
                                  D > 55%

The instructor will request an Oral exam in borderline cases.

Weighting: Homeworks   30
                          Mid-term Exam (Take-home)   15
                          Second Exam (date TBD)   30
                          Project (Written and Oral)   25

Notes:
1. The final is comprehensive.
2. The presentation must be accompanied by a written report. The visual aids (slides) used for the presentation must also be submitted. The format of the written report will depend on whether it is a report primarily on analysis of data, or a literature review. The length should be between 4 and 12 pages, including the reference list. It must include a Summary or Abstract, an Introduction, Conclusions, and a list of References cited. The main part of the report may follow the pattern of Methods-Results-Discussion, or, for a review, it may be divided into whatever sections make sense for the chosen topic. The 25 points for the Project are divided up as 3 points for the Initial Oral Report, 4 points for the Final Oral report and 18 points for the Written report.
3. The criteria for the Oral reports are: a) Technical correctness, b) Presentation Style, c) Legibility of Slides and d) Ability to answer questions.

Desired Outcomes for Students* in the MSE Program

MSE Program Outcomes	27-750
A. The ability to apply a knowledge of mathematics, physics, chemistry, materials and statistics to identify, formulate and solve the problems encountered in the production or application of a material.	H
B. An ability to apply core concepts in materials science (structure, properties, processing and performance) to materials engineering problems.	I
C. An ability to communicate effectively.	I
D. An ability to design and conduct experiments with an emphasis on relating properties and processing to structure.	L
E. An ability to relate materials selection and performance to design of engineered systems and components.	I
F. An ability to function responsibly and ethically in a professional, multidisciplinary environment and as an individual or as a member of a team.	I
G. An ability to employ the techniques, skills and tools of modern engineering practice in materials engineering.	H
H. Recognition of the need for lifelong scholarship.	I
I. A knowledge of contemporary issues.	L
J. The broad education necessary to understand the impact of engineering solutions in a global and societal context	L

H indicates that the course is expected to strongly support the outcome; I indicates intermediate support; L indicates that the course is expected to have a lesser impact on the outcome.

* This table is directed to undergraduate students but may also be of interest to graduate students.

General Policies

Expectations

The following guidelines will create a comfortable and productive learning environment throughout the semester.

You can expect me:

      To start and end class on time.

      To reply to e-mails within 24 hours on weekdays and 48 hours on weekends.

      To assign homework that adequately covers the material and meets the learning objectives of the course while adhering to the time expectations for a 9 unit course.

      To give exams that reflect accurately the material covered in class and assigned in homework.

      To be reasonable in asking question of students in class.

I expect you as students:

      To seek help when appropriate.

      To be attentive and engaged in class, including answering questions from the instructor.

      To spend an adequate amount of time on the homework each week, making an effort to solve and understand each problem.

      To come to class on time.

      To refrain from using laptops, cell phones and other electronic devices during class.

      To engage with both the abstract and computational sides of the material.

Some of these expectations are based on research on learning that shows that unexpected noises and movement automatically divert and capture people's attention, which means you are affecting everyone's learning experience if your cell phone, pager, laptop, etc. makes noise or is visually distracting during class.

Your One and Only Warning:
Zero Tolerance of Cheating & Plagiarism

Plagiarism means using words, ideas, or arguments from another person or source without citation. Cite all sources consulted to any extent (including material from the internet), whether or not assigned and whether or not quoted directly. For quotations, four or more words used in sequence must be set off in quotation marks, with the source identified.

Any form of cheating will immediately earn you a failing grade for *the entire course*. By remaining enrolled, you consent to this policy. I will seek the harshest penalties under CMU's policy on "Standards for Academic and Creative Life" and "Cheating and

Plagiarism" in the *Student Guidebook* (aka *The Word*, online at
http://synergy.as.cmu.edu.edu/Student_Affairs/handbook/).

Read it now.
Here are some examples of acceptable collaboration:

Clarifying ambiguities or vague points in class handouts, textbooks, or lectures.

Discussing or explaining the general class material.

Discussing the assignments to better understand them.

Getting help from anyone concerning issues which are clearly more general than the specific assignment.

Now for the dark side. As a general rule, if you do not understand what you are handing in, you are probably cheating. If you have given somebody the answer, you are probably cheating. In order to help you draw the line, here are some examples of clear cases of cheating:

Copying (assignment) documents from another person or source, including retyping their files, and copying anything without explicit citation from previously published works (except the textbook), etc.

Allowing someone else to copy your written assignment, either in draft or final form.

Getting help from someone whom you do not acknowledge on your solution.

Copying from another student during an exam, quiz, or midterm. This includes receiving exam-related information from a student who has already taken the exam.

Writing, using, or submitting a program that attempts to alter or erase grading information or otherwise compromise security.

Inappropriately obtaining course information from instructors and TAs.

Looking at someone else's files containing draft solutions, even if the file permissions are incorrectly set to allow it.

Receiving help from students who have taken the course in previous years.

Lying to course staff.

Copying on quizzes or exams.

Reviewing any course materials from previous years.

Reading the current solution (handed out) if you will be handing in the current assignment late.

Attendance and Participation Policy

Class Presence and Participation. Class presence and participation points are given to encourage your active class participation and discussion. You will be rewarded with a perfect score as long as you frequently come to class and actively contribute to the class discussion during recitations and lectures.

Presence: Although it is not required, most students send their professor a brief e-mail to explain their absence in advance. Students who repeatedly arrive late to the lecture or

recitation will have their Class Participation grade lowered. Please sign the attendance sheet when you come to the class. Any false signatures will result in zero participation grades for all parties involved.

Participation: The instructor expects students to follow the development of ideas and derivations. Any student may be asked at any time to complete a statement, answer a question, come up the to board to continue a derivation or explain a concept that has been covered in the class. Active participation by students in the learning process is well-known to enhance and reinforce learning.

How to Use Your Study Time More Efficiently

1.   Read your lecture notes over within 24 hours of lecture (or at least once before the next lecture).
        Highlight or make marginal notes for important words or concepts. This will help fix ideas and will help you to actively learn the material. This review takes about 20-30 minutes and really yields a large return.
        Re-do examples yourself, step by step, with pencil and paper. Examples often look easy when explained in class, but often turn out to be much harder when you do them yourself.
        Write down questions about things you do not understand. Bring these questions to lecture, lab, and to office hours and ask them.

2.   Lecture notes are provided for each class. Read them - if not before the class for which they are assigned then certainly after that class and before the next. Also, as you read, highlight, re-work examples yourself, and write down questions, as suggested above.

3.   **DO HOMEWORK PROBLEMS**. Actively doing problems is the *only* way to learn the material. Exam questions will be similar to homework problems.
        Start early. Do not leave assignments until the night before they are due.
        Try doing the problems yourself before discussing them with other people.

4.   *Use office visits* productively. Ask thoughtful questions about things that you do not understand. In other words, if you do (1)-(3) above, it will be much easier to isolate what is giving you trouble.

5.   *Review solutions* to assignments and exams. Just because you do not lose points on a homework question does not necessarily mean you fully understand the question and answer. Also, the solutions should serve as a model for how to write, using proper sentences and paragraphs, discussions and interpretations of data analyses.

6.   We will make every effort to help you learn the course material, but you must also make an effort to utilize the resources that are made available to help you. Please come talk to us – not only when you are having trouble but also when things are going well.

Students' Recording of Classes

Classroom activities may be recorded by a student for the personal, educational use of that student or for all students presently enrolled in the class only, and may not be further copied, distributed, published or otherwise used for any other purpose without the express written consent of the course instructor. All students are advised that classroom activities may be taped by students for this purpose.

BOOKS

Altmann, S. L. (1986). *Rotations, Quaternions and Double Groups*. Oxford, Clarendon Press.

Cullity, B. D. (1978). *Elements of X-ray Diffraction*, Addison-Wesley, Reading, Mass.

Bunge, H. (1982). *Texture Analysis in Materials Science*. London, Butterworths. (located in the reference section)

Gottstein, G. and L. S. Shvindlerman (1999). *Grain Boundary Migration in Metals*, CRC Press, Boca Raton, FL, ISBN 0-8493-8222-X. Note: 2nd edition is available.

Howe, J.M. (2000). *Interfaces in Materials*, Wiley Interscience, New York, NY, ISBN 0-471-13830-4.

Khan, A.S. and S. Huang, Continuum Theory of Plasticity. 1995, New York: Wiley-Interscience; ISBN 0471310433.

* Kocks, U. F., C. Tomé, and H.-R. Wenk, Eds. (1998). *Texture and Anisotropy*, Cambridge University Press, Cambridge, UK.

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Randle, V. and O. Engler (2000). *Texture Analysis: Macrotexture, Microtexture & Orientation Mapping*, Gordon & Breach, Amsterdam, Holland, ISBN 90-5699-224-4.

Reid, C. N. (1973). *Deformation Geometry for Materials Scientists*. Oxford, UK, Pergamon.

Sutton, A. P. and R. W. Balluffi (1995). *Interfaces in Crystalline Materials*. Clarendon Press, Oxford, UK.

Torquato, S., *Random Heterogeneous Materials: Microstructure and Macroscopic Properties*. 2001, New York: Springer Verlag, ISBN: 0387951679.

Underwood, E. E., *Quantitative Stereology*, (1970), Addison Wesley Longman, ISBN: 0201076500.

Links: a sampling from a recent search in Google with "crystallographic texture".

Texture (crystalline) - Wikipedia, the free encyclopedia
In materials science, texture is the distribution of crystallographic ... The full 3-dimensional representation of crystallographic texture is given by the ...
en.wikipedia.org/wiki/Texture_(crystalline) - 27k -
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Texture and Anisotropy of Crystalline Materials
Since nearly 20 years I am dealing with crystallographic textures. This are not the pictures of covered bodies, which are used as background in web-pages ...
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Crystallographic Texture of Stress-Affected Bainite
MAP_STEEL_TEXTURE, PROGRAM: Calculation of the crystallographic texture obtained when austenite transforms into martensite. The austenite itself can be ...
www.msm.cam.ac.uk/phase-trans/2007/texture_bainite.html - 10k

Crystallographic Texture
Crystallographic Texture of Stress-Affected Bainite; Crystallographic Texture and Intervening Transformations; Transformation Texture, Stainless Steel ...
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(IUCr-Crystallographic Education Online) Educational Resources
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Texture of materials using x-ray and neutron diffraction): ...
www.ccp14.ac.uk/solution/pole_figure/index.html - 18k -
Cached - Similar pages

An Analysis of the Influence of Crystallographic Texture on ...
Scientific.Net: An Analysis of the Influence of Crystallographic Texture on Residual
Stress Estimation for Metallic Films and Coatings.
www.scientific.net/An+Analysis+of+the+Influence+of+Crystallographic+Texture+on+Resi
dual+Stress+Estimation