2016 Spring

"Advanced Physical Metallurgy"

- Bulk Metallic Glasses-

03.02.2016

Eun Soo Park

Office: 33-313
Telephone: 880-7221
Email: espark@snu.ac.kr
Office hours: by appointment

Introduction

- **Web lecture assistance: http://etl.snu.ac.kr**
  - All materials will be posted at the webpage.
  - text message will be sent for the important and urgent notice.

- **Hand out copied materials or scanned materials in website**

Text: “Bulk Metallic Glasses”, C. Suryanarayana, A. Inoue,
CRC Press, Taylor & Francis Group (2011)

References: 1) "Metallic Glasses", P. Duwez et al.
American Society for Metals, Metals Park, Ohio (1976)

2) “Amorphous Metallic Alloys”, F.E. LUBORSKY
Butterworths & Co. (Publishers) Ltd. (1983)

3) "Bulk Metallic Glasses", M.K. Miller, P.K. Liaw,
Springer (2008)

Additional reading materials will be provided.

Course Goals

This course will cover the rapidly evolving field of amorphous materials, with a particular emphasis on the connection among thermodynamic, kinetic, and structural aspects of amorphous materials. This course intends to illustrate the major materials issues for amorphous metals, from processing to properties and from the fundamental science of glasses to viable industrial applications. I hope that this course shows why amorphous materials are attracting such an intensive interest and serve to highlight some challenging issues awaiting resolution. After completing this course, students performing experimental research using amorphous materials should be reasonably informed about materials preparation, processing, and stability. Students performing research outside this field should be able to consider amorphous materials as a new form of material suitable for selection in their innovations.

Schedule

week 1 Introduction to Amorphous materials

week 2 Classification of Solids

week 3 Definition of Amorphous Materials

week 4 Preparation of Amorphous Materials

week 5 Phase Transition: glass transition

week 6 Measurement of Glass Transition Temperature

week 7 Theories for the Glass Transition I: thermodynamic / entropy

week 8 Theories for the Glass Transition II: relaxation behavior / viscosity

week 9 Structural Approach to Glass Formation

week 10 Kinetic Approach to Glass Formation

week 11 Ease of Glass Transition: glass-forming ability

week 12 Glass Forming Ability Parameters

week 13 Formation of Bulk Metallic Glasses

week 14 Mechanical Properties of Bulk Metallic Glasses and Their Composites

week 15 Unique Properties of of Bulk Metallic Glasses

week 16 Potential Applications of Bulk Metallic Glasses

Components of Your Grade:

1) Exams (mid: 35% + final: 40%)

There will be two exams, each of which takes place in class for 3 hours. The exams will be conceptual and simple.

2) Reports and Presentation (15%) (+Incentive Homework 5%)

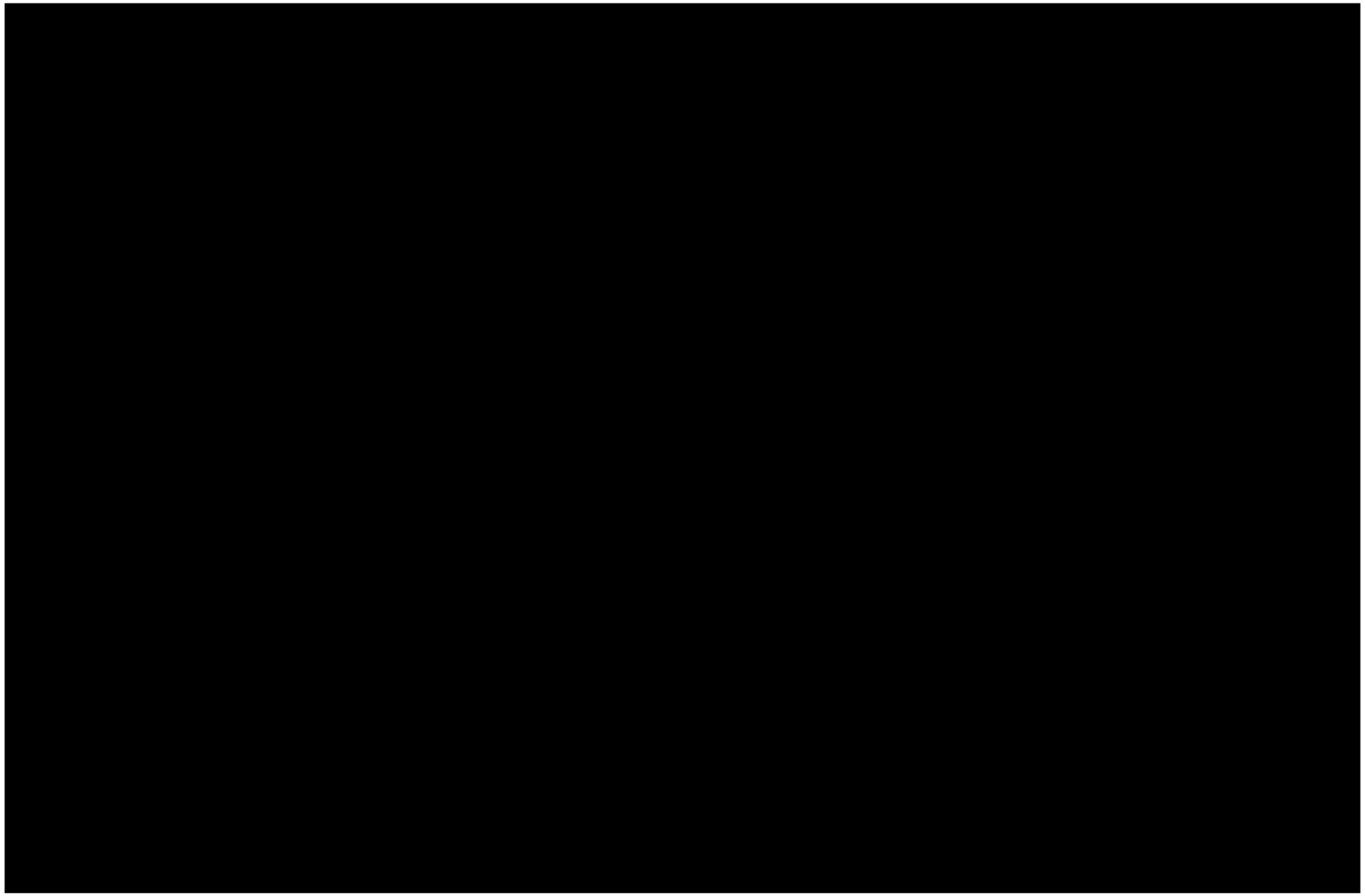
There will be one presentation on the topics of amorphous materials in the last part of course, which takes place in class for half an hour. The presentation will include mainly topics of amorphous materials from the fundamental science to viable industrial applications.

3) Attendance (10%)

Please don't be late to class.

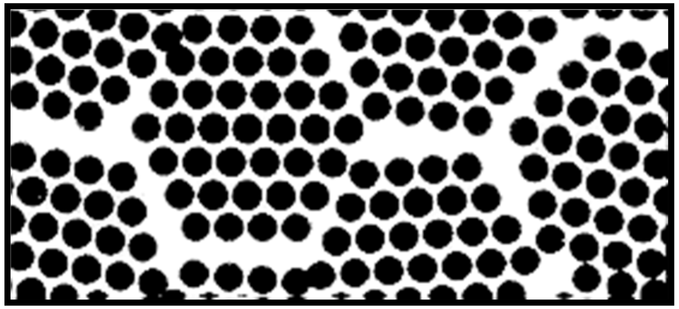
REMARK: The grade components might change up to 5% depending on the student's achievement.

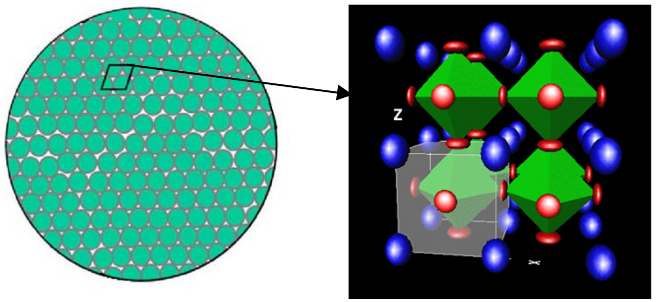
Bulk Metallic Glass: the 3rd Revolution in Materials?



Structure of crystals, liquids and glasses

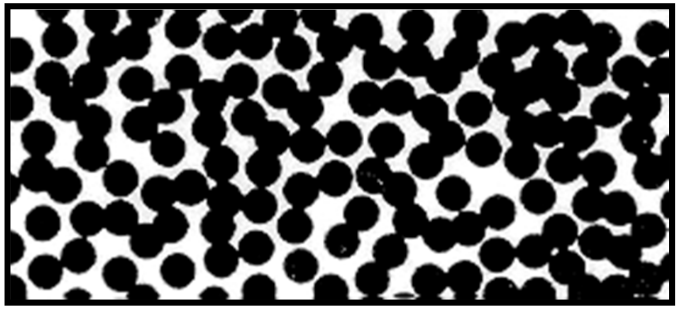
Crystals

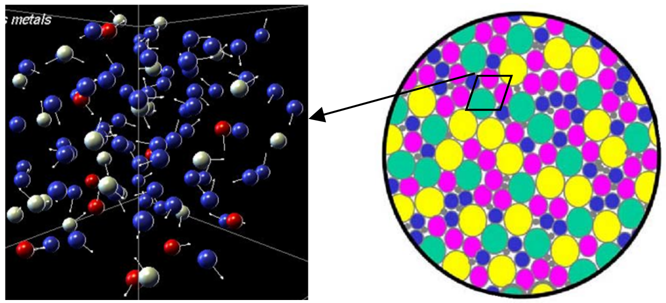




• periodic
• grain boundaries

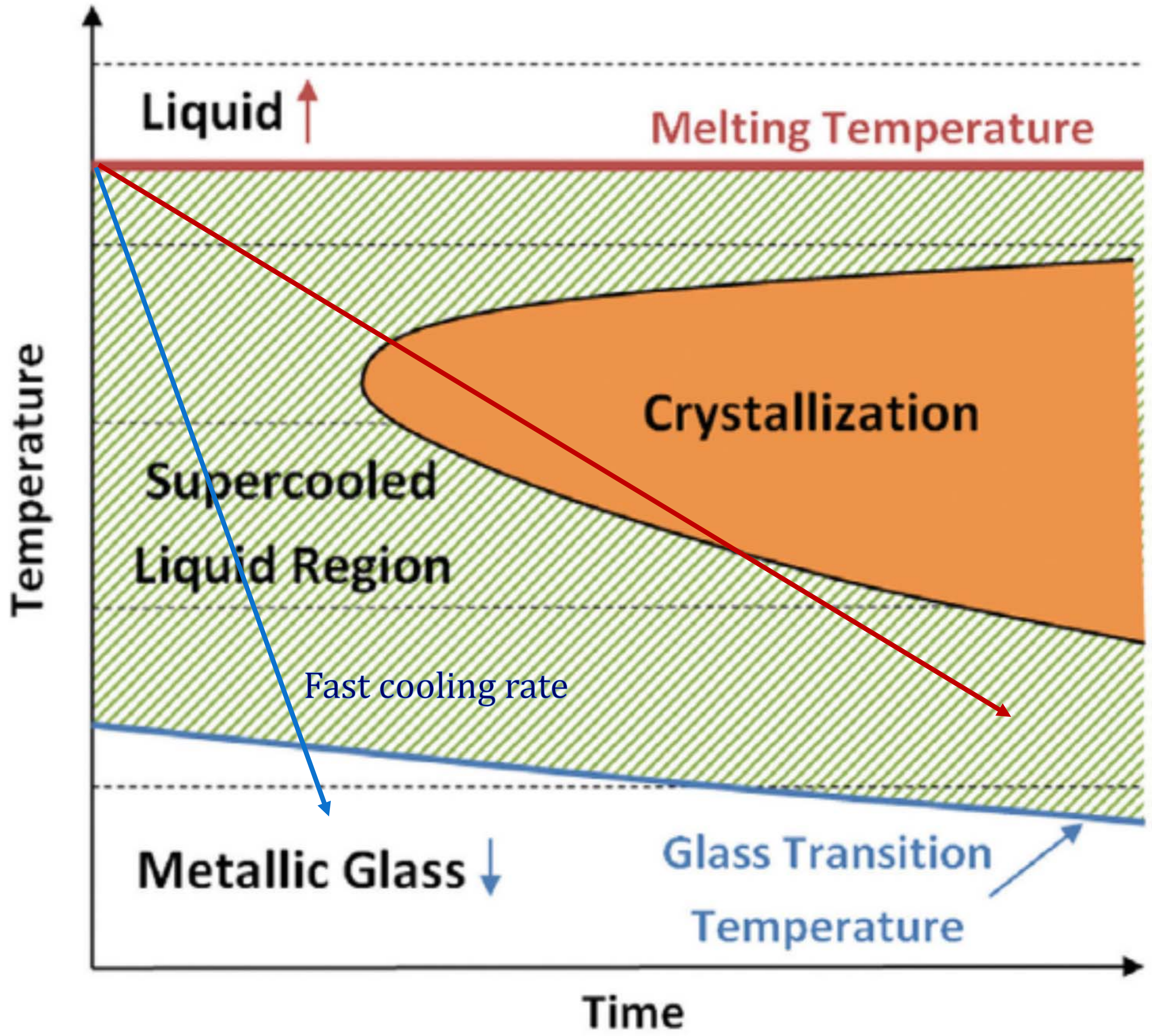
Liquids, glasses





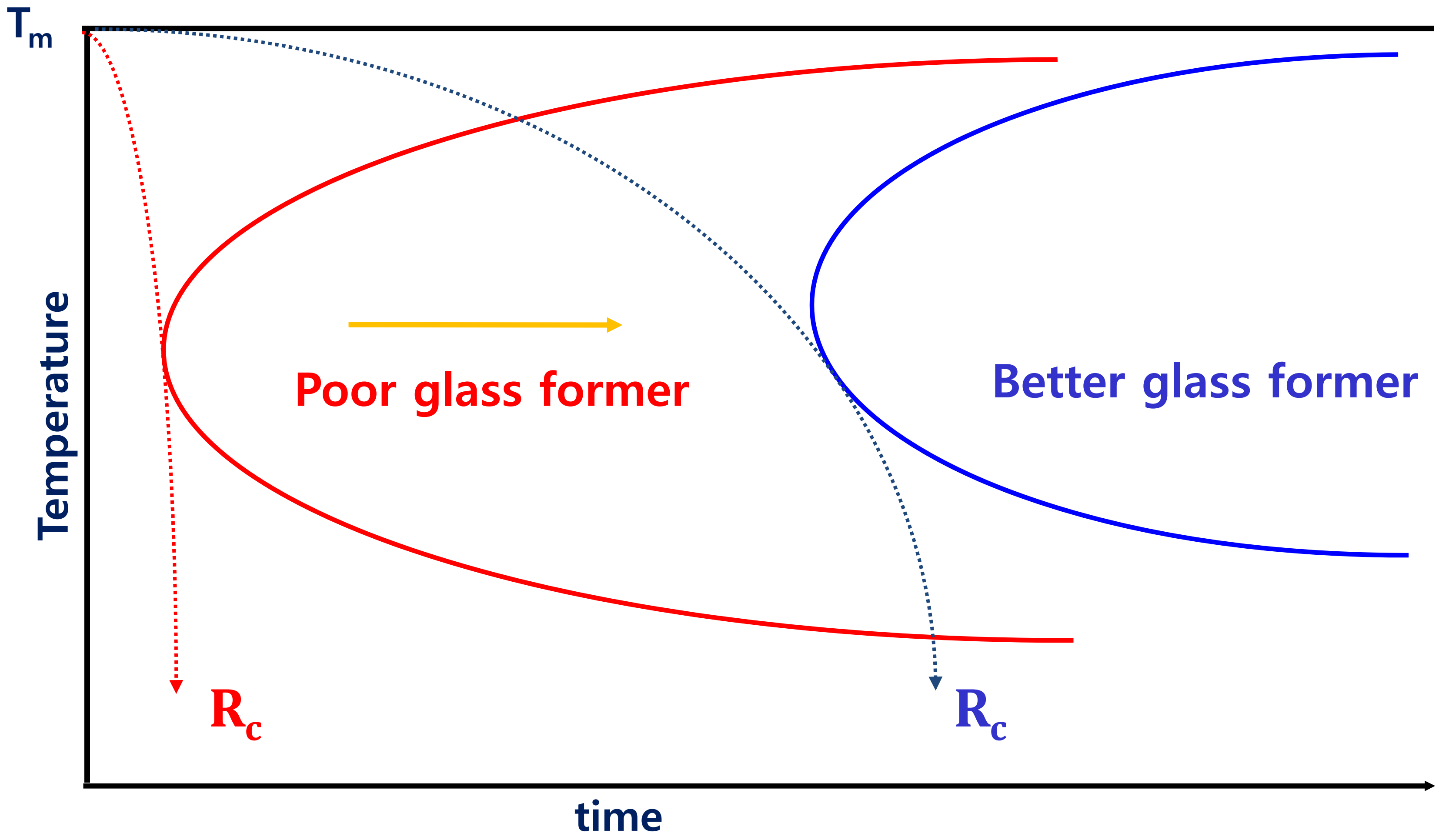
• amorphous = non-periodic
• no grain boundaries

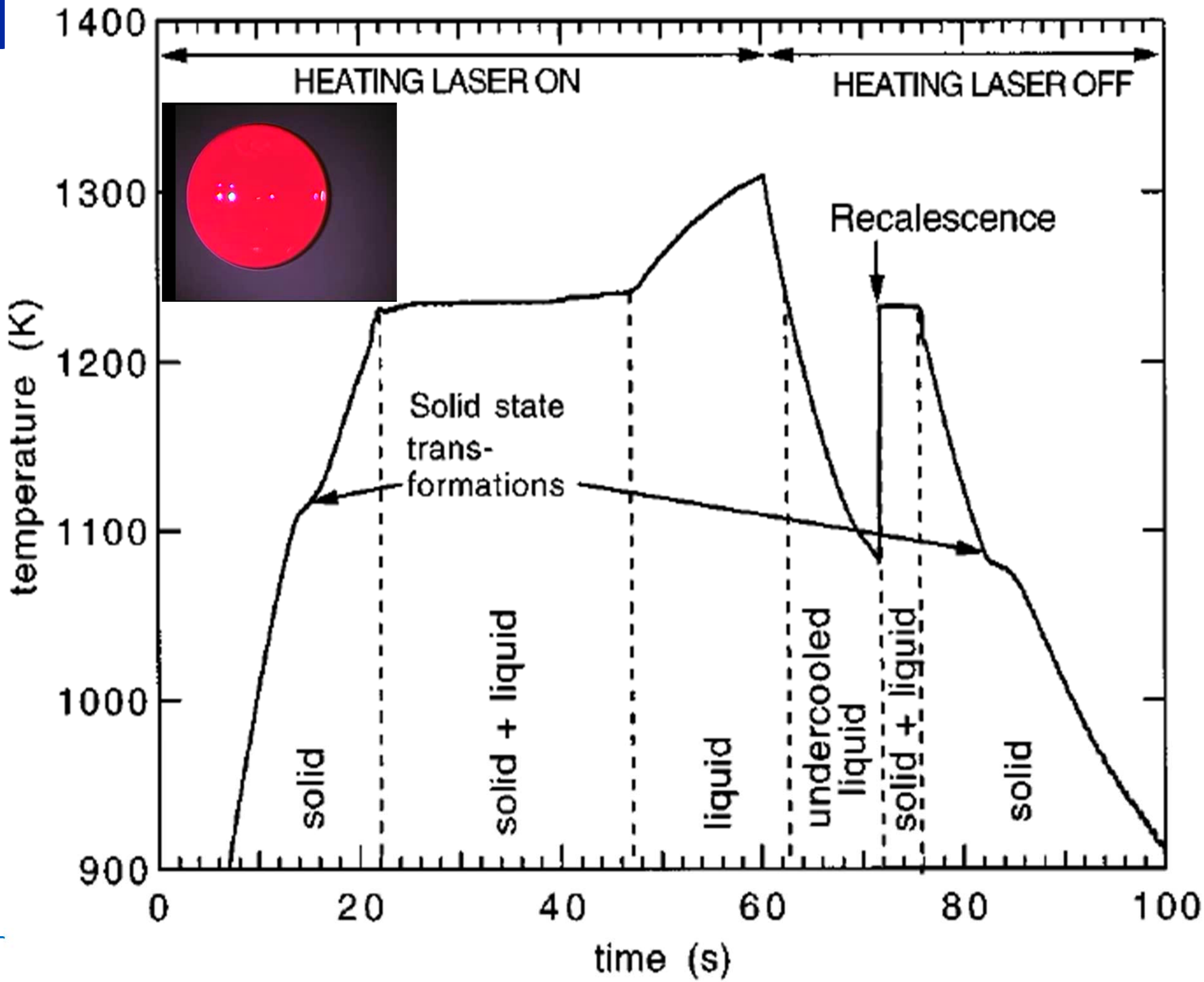
Glass formation : (1) Fast Cooling



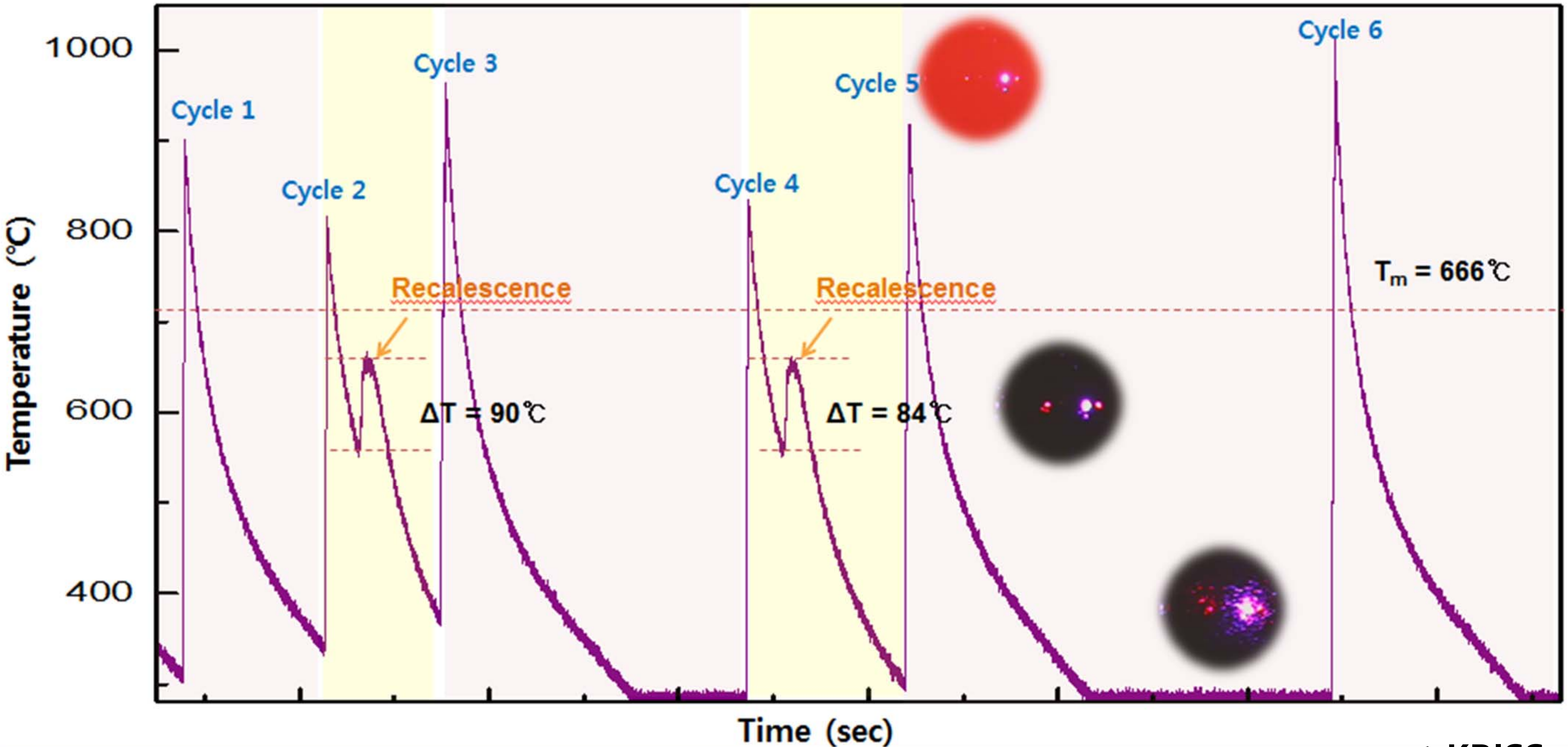
Glass formation : (2) Better Glass Former

GFA $R_c = \frac{\Delta T}{t_n}$ undercooled liquid → crystalline




HEATING LASER ON
HEATING LASER OFF
Recalescence
Solid state
trans-
formations
solid
solid + liquid
liquid
undercooled
liquid
solid + liquid
solid
temperature (K)
1400
1300
1200
1100
1000
900
0
20
40
60
80
100
time (s)

Electrostatic Levitation: cooling curve of Vitreloy 1 system



at KRISS

Amorphous Materials

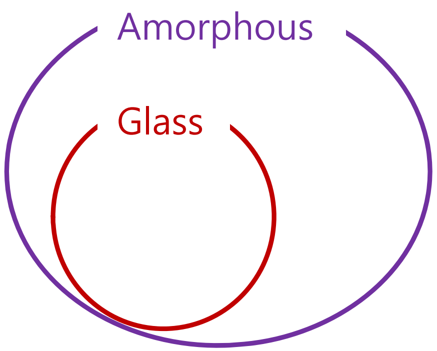
- **Amorphous materials**

  a wide diversity of materials can be rendered amorphous indeed almost all materials can.

- **metal, ceramic, polymer**

- **glassy/non-crystalline material**

cf) amorphous vs glass
- random atomic structure (short range order)
- showing glass transition.

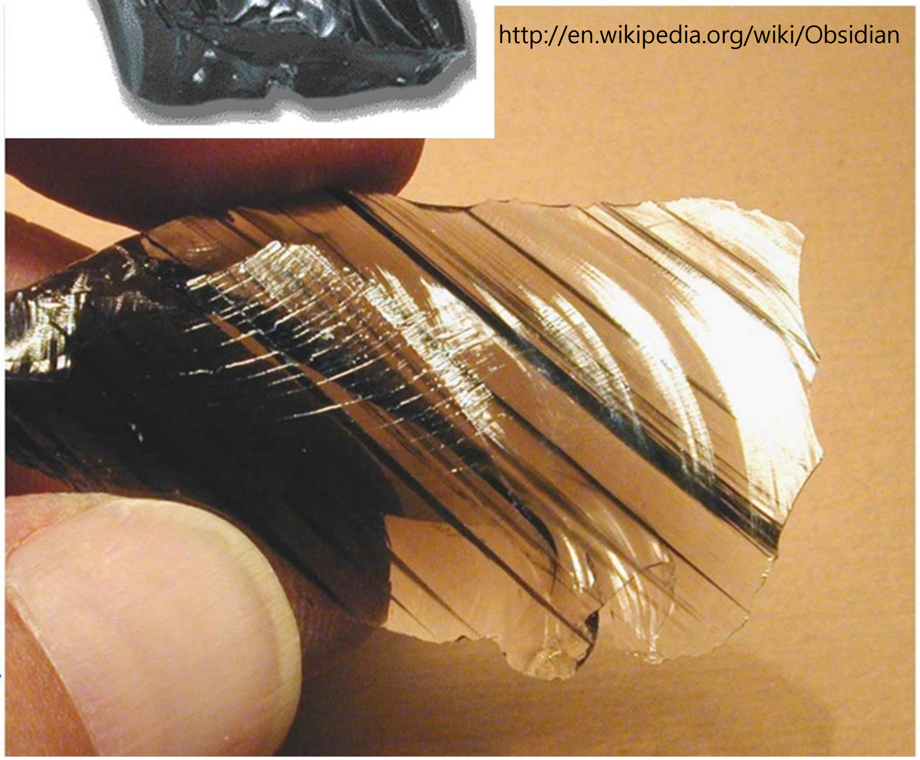


- retain liquid structure

- rapid solidification from liquid state

Glassmaking by humans can be traced back to 3500 BCE in Mesopotamia (current Iraq).

Obsidian is a naturally occurring volcanic glass formed as an extrusive igneous rock. It is produced when felsic lava extruded from a volcano cools rapidly with minimum crystal growth. Obsidian is commonly found within the margins of rhyolitic lava flows known as **obsidian flows**, where the chemical composition (high silica content) induces a high viscosity and polymerization degree of the lava. The inhibition of atomic diffusion through this highly viscous and polymerized lava explains the lack of crystal growth. Because of this lack of crystal structure, sharp obsidian blade edges can reach almost molecular thinness, leading to its ancient use as projectile points and cutting and piercing tools, and its modern use as surgical scalpel blades.



http://en.wikipedia.org/wiki/Obsidian

First Amorphous Metals: evaporation method

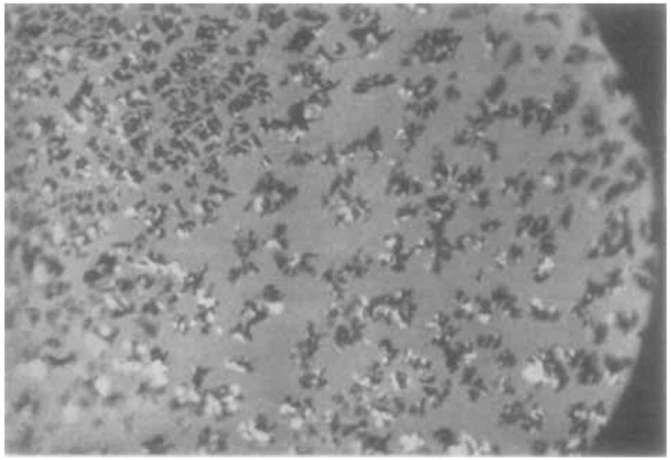
Über nichtleitende Metallmodifikationen[1])

Von Johannes Kramer

(Mit 8 Figuren)

Das metallische Leitvermögen wird bekanntlich auf das Vorhandensein freibeweglicher Elektronen und damit auch ortsgebundener positiver Ionen zurückgeführt. Da nun ein nichtionisierter Metalldampf ein vollkommener Nichtleiter ist, so liegt die Vermutung nahe, daß es bei Kondensation eines solchen Dampfes gelingen müßte, nichtleitende Schichten zu erhalten, wenn Wechselwirkungen zwischen den regellos aufeinandergepackten Atomen vermieden werden könnten. Man hätte es dann mit einem Gebilde zu tun, das als völlig amorph anzusehen wäre und in seiner Konstitution am ehesten einem hochkomprimierten Gase entspräche.

J. Kramer
Nonconducting modifications of metals. Ann. Physik (Berlin, Germany) 19, 37 (1934)



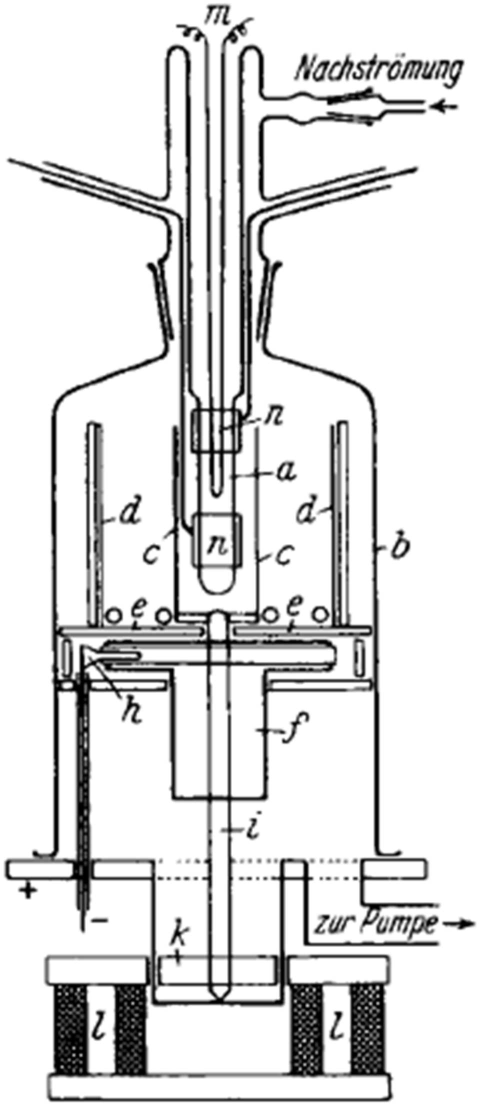
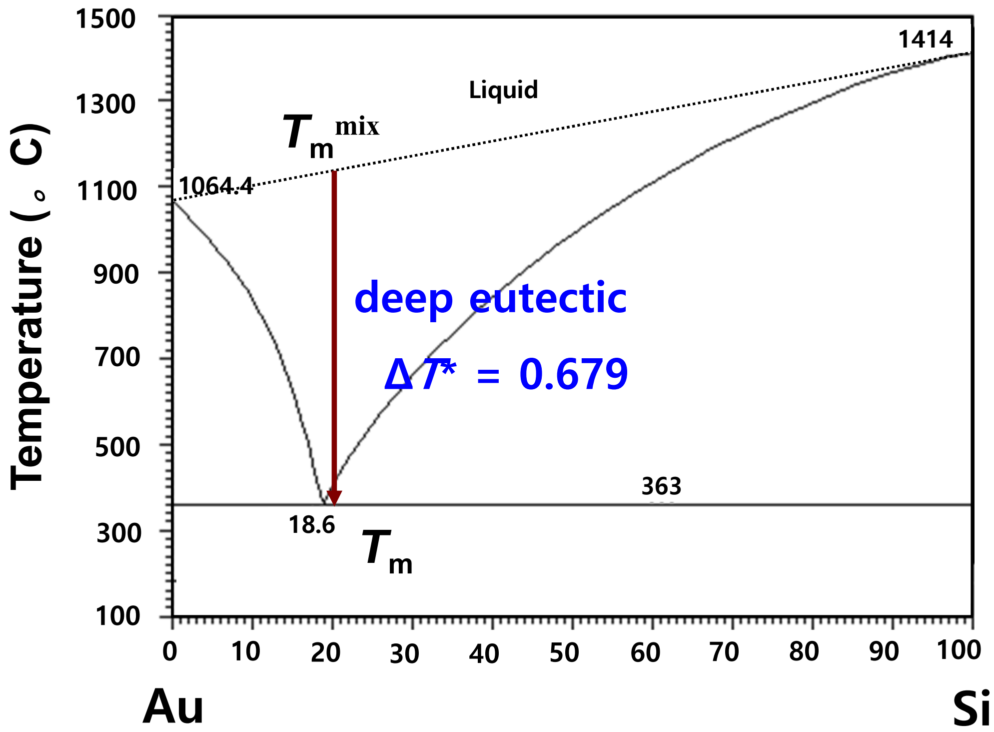


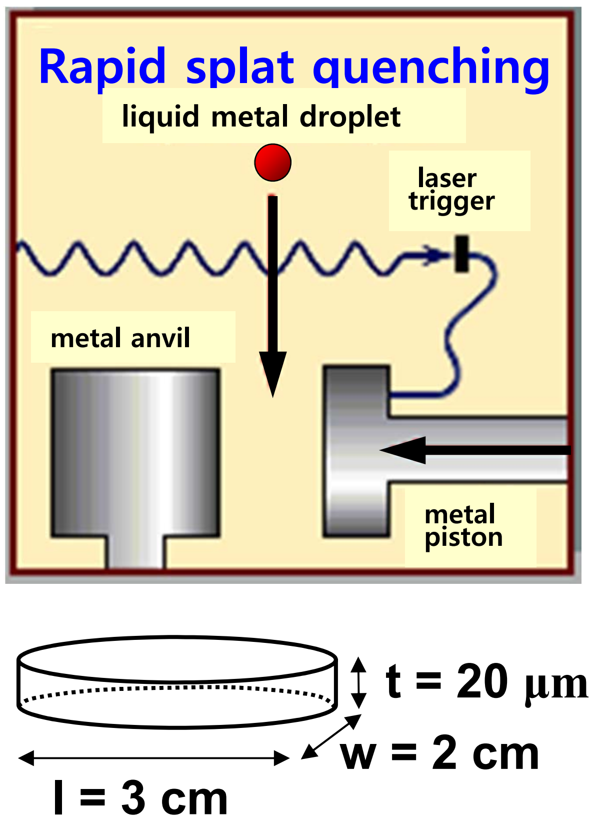
Fig. 1.
Zerstäubungsapparatur

Glass formation : stabilizing the liquid phase

- First metallic glass ($Au_{80}Si_{20}$) produced by splat quenching at Caltech by Pol Duwez in 1960.

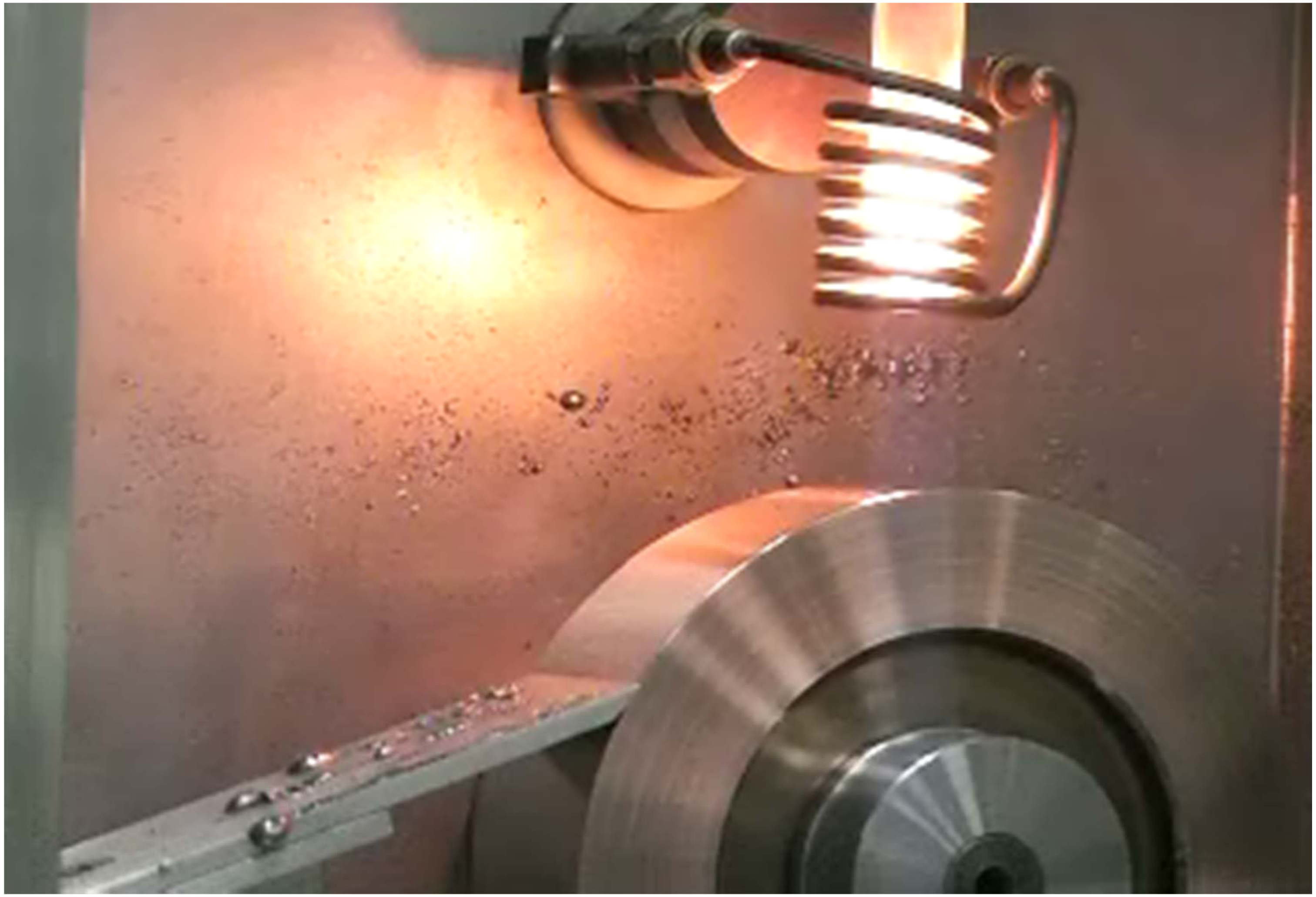


W. Klement, R.H. Willens, P. Duwez, Nature 1960; **187**: 869.



Glass formation : rapid quenching of liquid phase

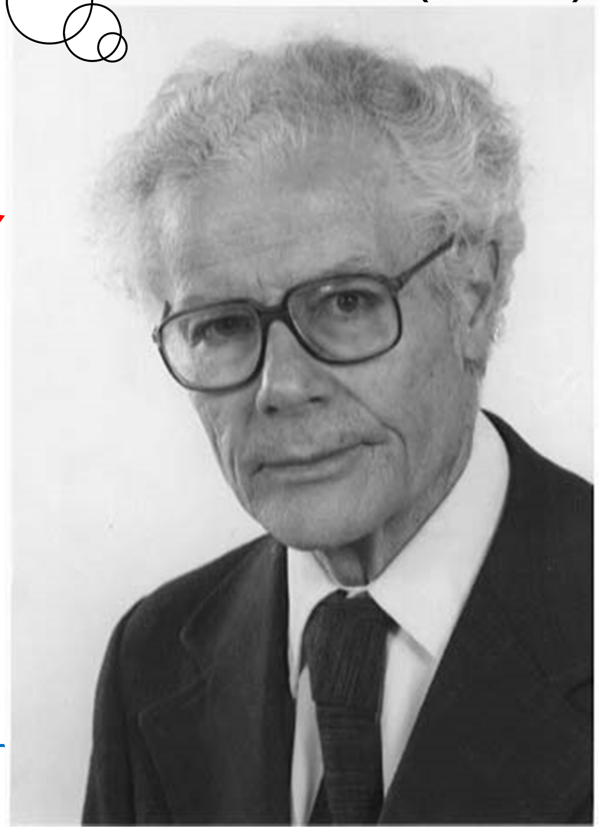
- 1969 Ribbon type with long length using melt spinner : FePC, FeNiPB alloy



Bulk formation of metallic glass

By eliminating or reducing the effectiveness of heterogeneous nucleation sites, it should be possible to form bulk metallic glasses with virtually unlimited dimensions.

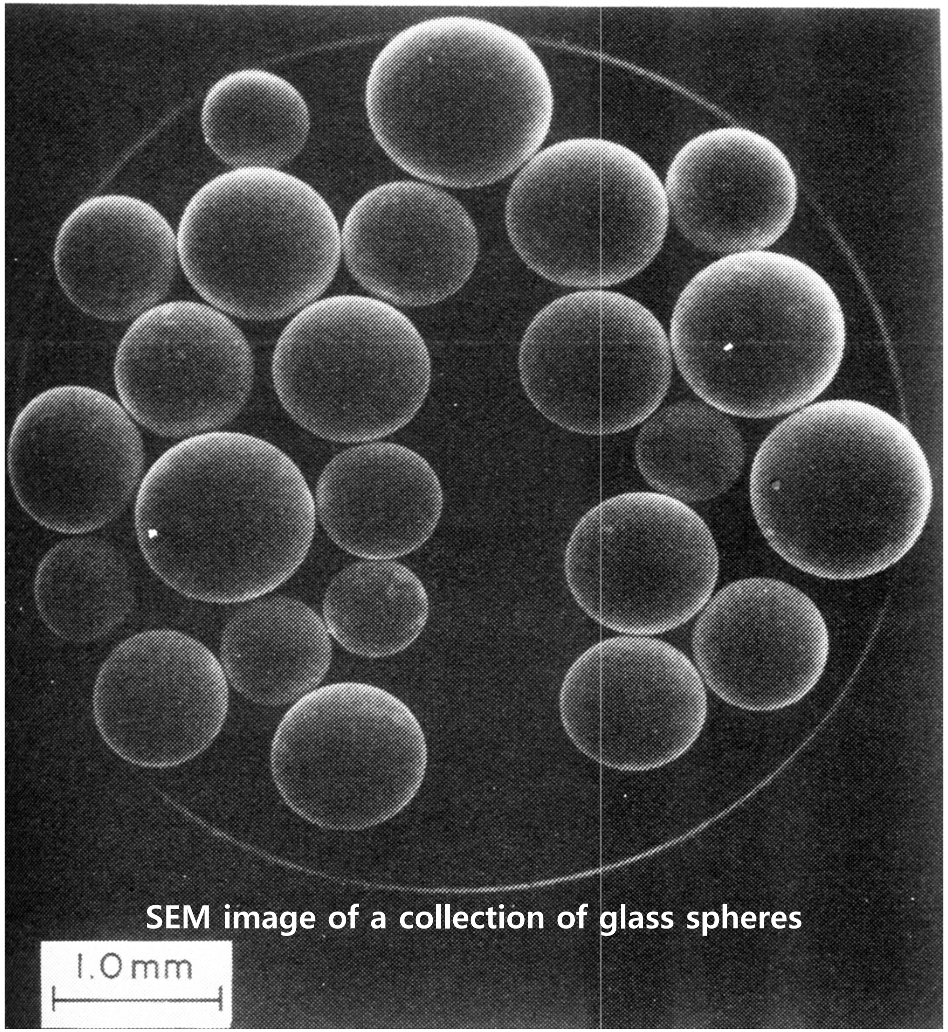
David Turnbull (Harvard)



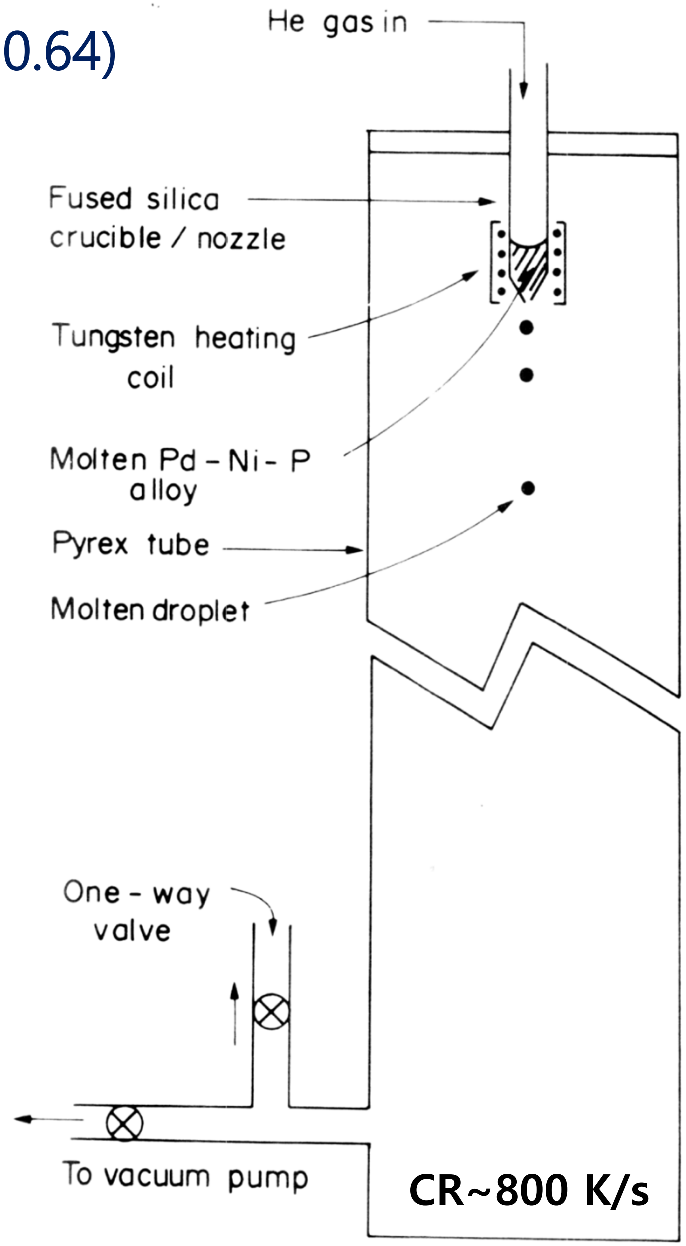
Bulk formation of metallic glass

- First bulk metallic glass: $Pd_{77.5}Cu_6Si_{16.5}$ (T_{rg}=0.64)

By droplet quenching (CR~800 K/s)



SEM image of a collection of glass spheres

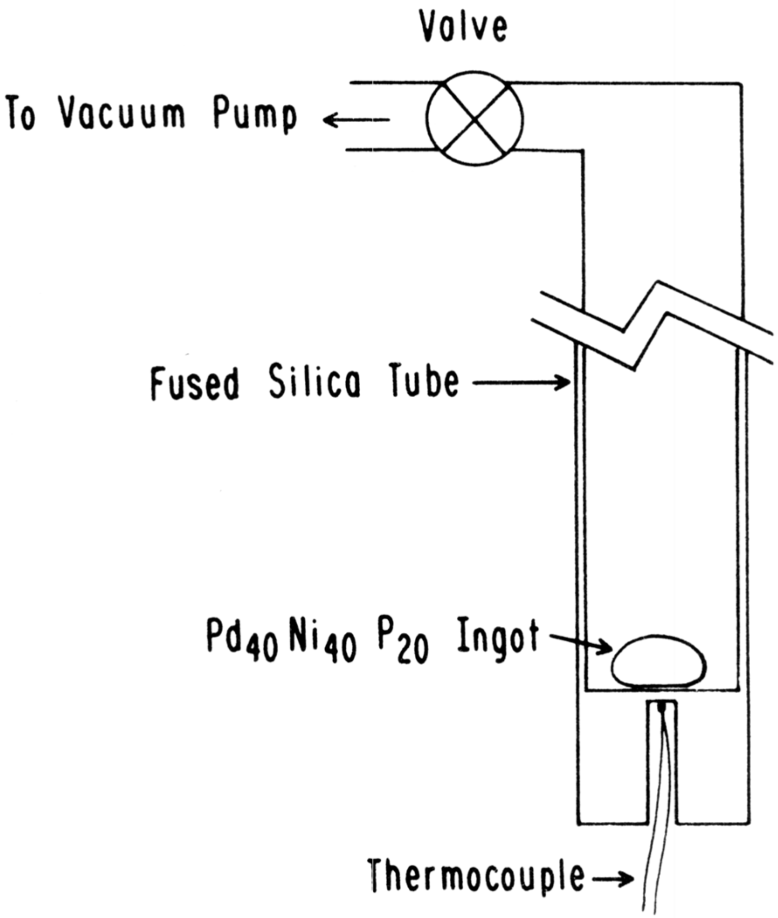


CR~800 K/s

Bulk formation of metallic glass

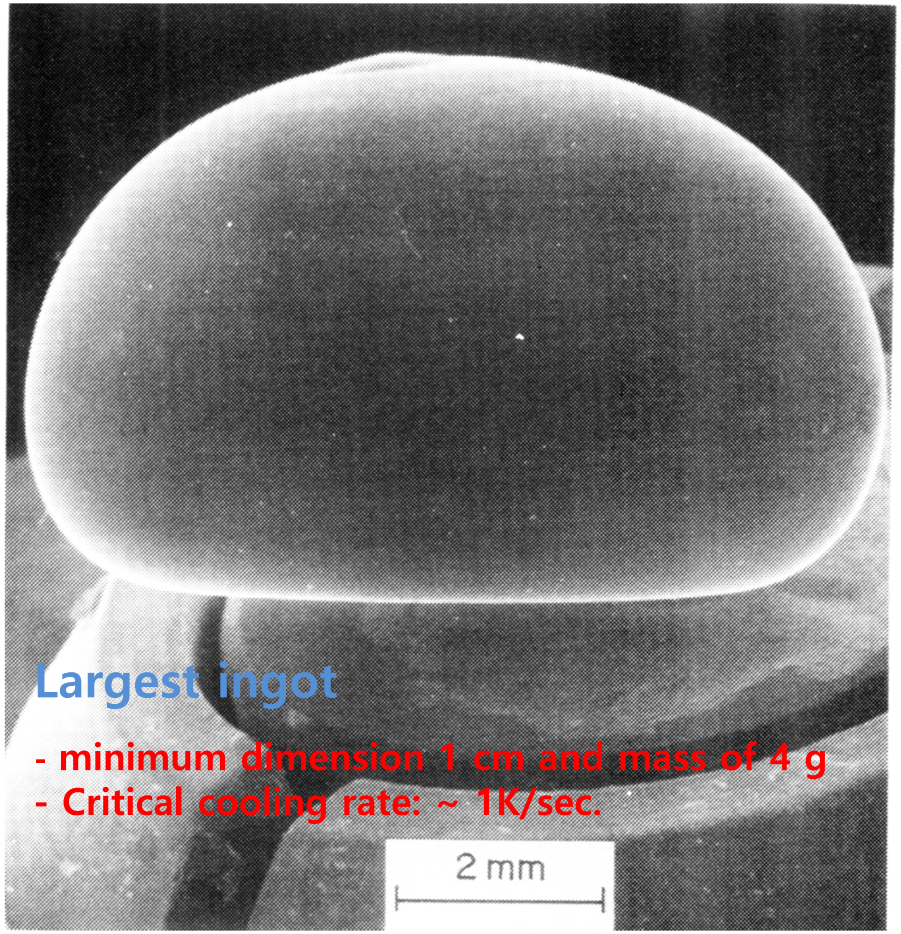
- First bulk metallic glass
  $Pd_{77.5}Cu_6Si_{16.5}$ (T_{rg}=0.64)

- Alloy Selection: consideration of T_{rg}
  $Pd_{40}Ni_{40}P_{20}$ (T_{rg}=0.67)

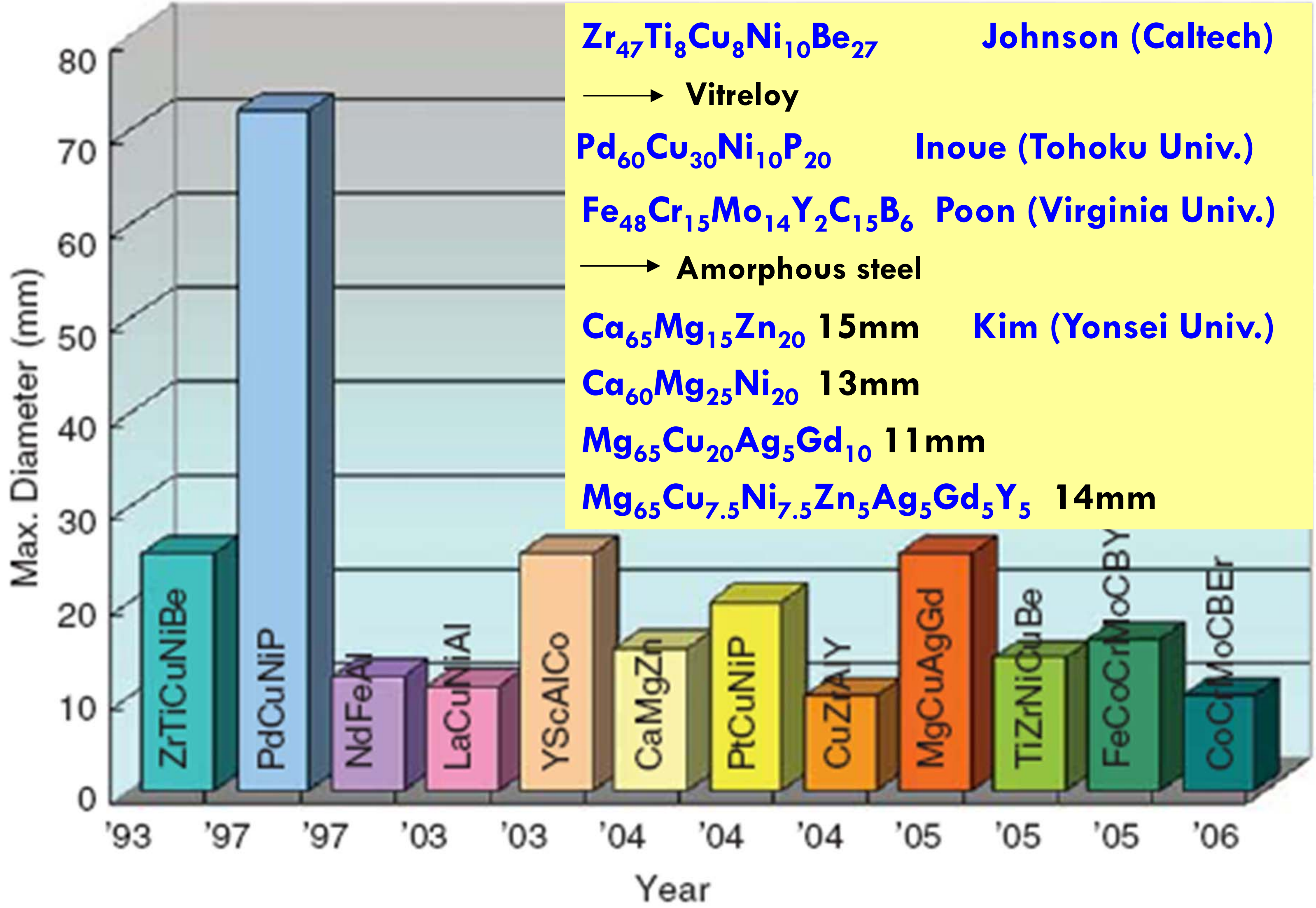


<Schematic diagram of apparatus>

Suppression of heterogeneous nucleation



Recent BMGs with critical size ≥ 10 mm



$Zr_{47}Ti_8Cu_8Ni_{10}Be_{27}$ Johnson (Caltech)

→ Vitreloy

$Pd_{60}Cu_{30}Ni_{10}P_{20}$ Inoue (Tohoku Univ.)

$Fe_{48}Cr_{15}Mo_{14}Y_2C_{15}B_6$ Poon (Virginia Univ.)

→ Amorphous steel

$Ca_{65}Mg_{15}Zn_{20}$ 15mm Kim (Yonsei Univ.)

$Ca_{60}Mg_{25}Ni_{20}$ 13mm

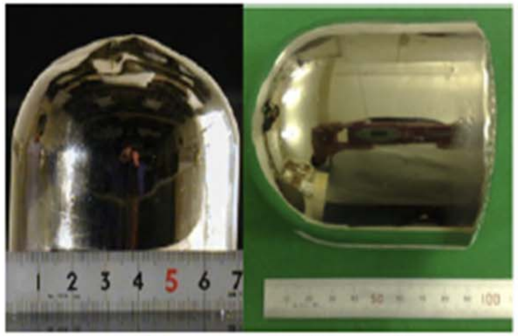
$Mg_{65}Cu_{20}Ag_5Gd_{10}$ 11mm

$Mg_{65}Cu_{7.5}Ni_{7.5}Zn_5Ag_5Gd_5Y_5$ 14mm

Bulk glass formation in the Pd-/Ni-/Cu-/Zr- element system

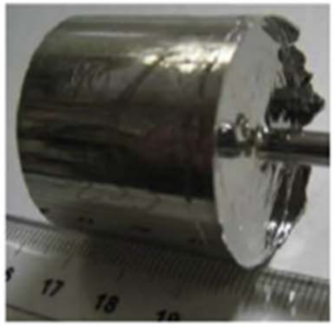
Massy Ingot Shape

(a) Pd-Cu-Ni-P



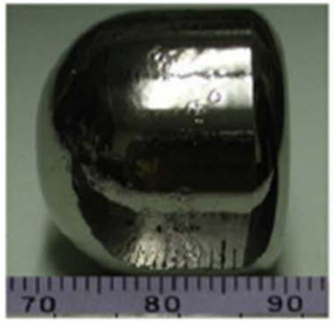
72ϕx 75 mm 80ϕx 85 mm

(b) Zr-Al-Ni-Cu



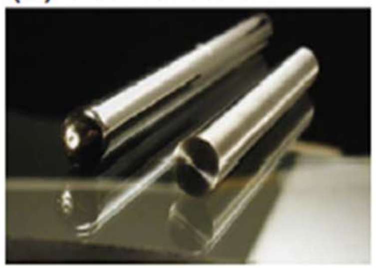
(c) Cu-Zr-Al-Ag

(d) Ni-Pd-P-B

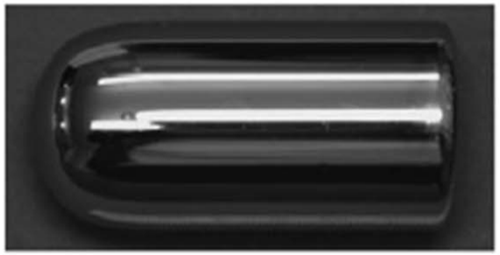


Cylindrical Rods

(e) Pd-Cu-Ni-P

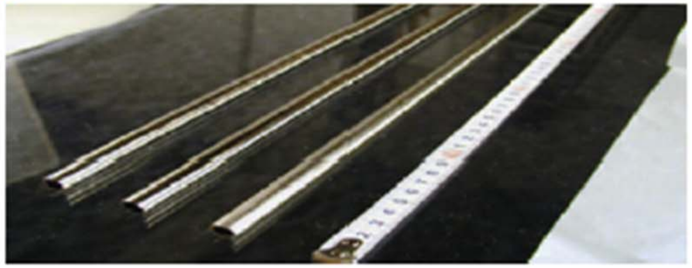


(f) Pt-Pd-Cu-P

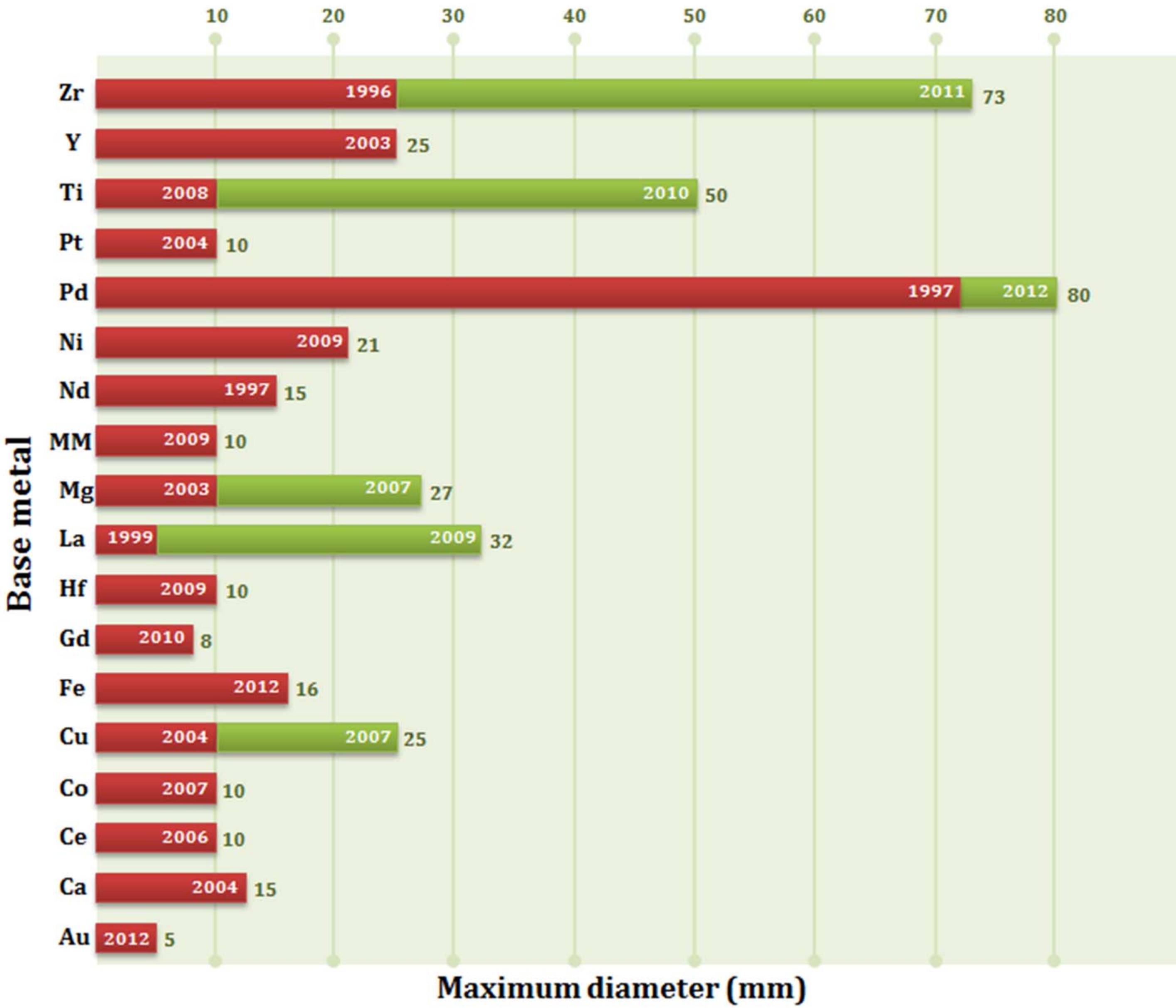


Hollow Pipes

(g) Pd-Cu-Ni-P



Recent BMGs with critical size ≥ 10 mm



Are amorphous metals useful?

"Homework 1":

Please find one of the advanced metallic materials and make a summary of the material within 3 pages ppt.

Submission due date: March 7, 2016

You may have a chance to discuss the materials in class

on March 9, 2016.