## 3. World's Smallest Ceramic QR Code – Science & Technology

Recently, researchers at TU Wien (public technical university) in Austria have set the Guinness World Record for creating the world's smallest QR code using ceramics. Guinness World Record- On December 3, the team set a Guinness World Record with a 2 $\mu m^2$ QR code, smaller than a bacterium and one-third the size of the previous record.

### 1. Concept of QR Code

1. A Quick Response (QR) Code is a two-dimensional (2D) matrix barcode capable of storing information in both horizontal and vertical directions.
2. Unlike traditional one-dimensional barcodes that store data only along a single line, QR codes use a grid of black and white squares (modules) arranged within a square matrix.
3. This structure enables QR codes to store significantly larger amounts of information.
4. Information that can be stored in QR codes includes-
    1. Text
    2. URLs
    3. Contact information
    4. Payment details
    5. Geographic coordinates
    6. Authentication or tracking data.
5. QR codes are designed for rapid decoding, allowing smartphones and scanners to retrieve information instantly.

### 2. Development and History

1. The QR code was developed in 1994 by the Japanese company Denso Wave, a subsidiary of the Toyota Group.
2. It was originally designed to track automobile parts during manufacturing.
3. Later research involving scientists such as Paul Mayrhofer, Erwin Peck, and Balint Hajas contributed to advanced miniaturisation techniques in QR-based storage experiments.
4. The technology was released as open and royalty-free, enabling rapid global adoption across industries.

### 3. Structural Components of a QR Code

A typical QR code contains several functional components that enable accurate scanning and decoding.

1. Finder Patterns
   Large square patterns located at three corners that help scanners determine orientation.
2. Alignment Patterns
   Smaller patterns that correct distortion when the QR code is scanned from different angles.
3. Timing Patterns
   Alternating black and white modules that define the size of the data grid.
4. Data Modules
   The actual encoded information stored as binary data.
5. Error Correction Codes
   Enable recovery of information even if part of the QR code is damaged.

## 4. Data Capacity and Error Correction

1. QR codes use Reed–Solomon error correction, enabling data recovery even when the code is partially damaged.
2. Four levels of error correction are available-
    1. Level L – Recovers about 7% data loss.
    2. Level M – Recovers about 15%.
    3. Level Q – Recovers about 25%.
    4. Level H – Recovers about 30%.
3. Maximum storage capacity includes-
    1. Around 7,000 numeric characters
    2. Around 4,000 alphanumeric characters
    3. Around 3 KB of binary data

## 5. Limitations of Conventional Data Storage

1. Traditional data storage technologies include-
    1. Hard Disk Drives (HDDs)
    2. Magnetic tapes
    3. Optical discs (CDs and DVDs)
2. These technologies typically last 10–30 years, depending on storage conditions.
3. Major challenges associated with them include-
    1. Magnetic degradation
    2. Environmental damage
    3. Hardware obsolescence
    4. Data rot or bit rot
4. To address long-term data preservation challenges, researchers are exploring durable physical storage media, including ceramic-based data engraving.

## 6. Ion Beam Milling Method

**Concept**

1. Ion Beam Milling is a nanofabrication technique used to precisely remove material from a surface using a focused beam of high-energy ions.
2. The ions—commonly gallium ions—are accelerated toward the target surface.
3. When these ions strike the material, they dislodge atoms through a process called sputtering, allowing extremely precise pattern formation.

**Focused Ion Beam (FIB) Technology**

1. The most common implementation is Focused Ion Beam (FIB) milling, which allows manipulation of materials at the nanometre or atomic scale.
2. It is widely used in-
    1. Semiconductor fabrication
    2. Microelectronics
    3. Nanotechnology research
    4. Surface patterning

**Application in QR Code Fabrication**

1. Researchers used focused ion beam milling to engrave extremely tiny QR codes onto ceramic thin films.
2. Instead of ink printing, the QR code is physically etched into the material.
3. This makes the QR code-
    1. Extremely durable
    2. Resistant to environmental damage
    3. Suitable for long-term data storage.

**Materials Used**

1. A ceramic material called Chromium Nitride (CrN) was used for engraving nanoscale QR codes because of its-
    1. High hardness
    2. Corrosion resistance
    3. Structural stability.

## 7. Ceramics – Concept and Characteristics

**Definition**

1. Ceramics are inorganic, non-metallic materials produced by heating natural raw materials such as-
    1. Clay
    2. Silica
    3. Alumina
2. After shaping, these materials are hardened through high-temperature firing processes.

### Types of Ceramics

**Traditional Ceramics**

1. Pottery
2. Bricks
3. Tiles
4. Porcelain

**Advanced or Engineering Ceramics**

Used in high-technology applications such as-

1. Aerospace
2. Electronics
3. Biomedical engineering
4. Nanotechnology.

**Key Properties of Ceramics**

High Strength and Hardness

1. Ceramics possess exceptional hardness and resistance to-
    1. Abrasion
    2. Wear
    3. Scratching

Example-

Alumina ceramics used in cutting tools and ballistic armour.

**Thermal Stability**

1. Ceramics can withstand extremely high temperatures without melting or deforming.

2. They are suitable for high-temperature environments.

Example-

Zirconia ceramics used in jet engines and thermal barrier coatings.

**Chemical Resistance**

1. Ceramics resist corrosion and oxidation in harsh environments such as acids and alkalis.

Example-

Ceramic linings used in chemical plants.

**Electrical and Magnetic Properties**

1. Depending on composition, ceramics can function as-
    1. Electrical insulators
    2. Semiconductors
    3. Superconductors

Example-

Barium titanate used in capacitors and sensors.

**Wear Resistance and Durability**

1. Ceramics exhibit excellent long-term durability and mechanical stability.

Example-

Ceramic coatings used in industrial machinery.

## 8. Advantages of Ceramic-Based Data Storage

**Extremely Long Lifespan**

1. Magnetic storage media typically last 10–30 years.
2. Ceramic-based etched storage may last centuries or even thousands of years.

**Zero Energy Requirement**

1. Data stored through physical engraving does not require continuous electrical power.

Resistance to Data Degradation

1. Magnetic and electronic storage may suffer from bit rot or electromagnetic interference.
2. Ceramic engravings remain physically stable and permanent.

**Environmental Resistance**

Ceramic materials resist-

1. Heat
2. Moisture
3. Chemical corrosion
4. Electromagnetic radiation.

**Reduced Carbon Footprint**

1. Long-term passive storage reduces reliance on energy-intensive data centres.

## 9. Applications of Ceramics

**Traditional Applications**

1. Pottery and decorative objects
2. Bricks and construction materials
3. Tiles and porcelain products.

**Industrial and Engineering Applications**

1. Cutting tools and abrasives

2. Protective armour systems
3. Aerospace components
4. Heat shields and turbine parts.

## 10. Advanced and Emerging Applications

**Nanotechnology**

1. Nanoscale ceramic structures can enable ultra-dense data storage, such as microscopic QR codes.

**Biomedical Engineering**

1. Ceramic implants are used in-
    1. Hip replacements
    2. Dental implants
    3. Bone substitutes.

**Electronics**

1. Ceramic materials are used in-
    1. Capacitors
    2. Superconductors
    3. Sensors
    4. Semiconductor substrates.

## Conclusion

QR codes represent a versatile data storage and information retrieval technology widely used across industries. Advances in ion beam milling and ceramic nanotechnology have opened new possibilities for ultra-durable long-term data storage, far exceeding the lifespan of conventional digital media. As technologies evolve, ceramic-based nanoscale QR codes could play an important role in archival storage, data preservation, and next-generation nanotechnology applications.

Source- https-//www.thehindu.com/sci-tech/science/tiny-qr-code-sets-guinness-record-aims-for-long-term-data-storage/article70694983.ece