Y/AMT-411

Y-12

Project Accomplishment Summary
for
Project Number 92-Y12P-027-B2

OAK RIDGE
Y-12
PLANT

LOCKHEED MARTIN

METALLIZATION TECHNOLOGY FOR TENTH-MICRON RANGE INTEGRATED CIRCUITS

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DISCLAIMER

PROJECT ACCOMPLISHMENT SUMMARY

Title: Metallization Technology for Tenth-Micron Range Integrated Circuits
DOE TTI Number: 92-Y12P-027-B2
CRADA Number: ORNL92-0104
Partner: International Business Machines, Inc. (IBM)

BACKGROUND

A critical step in the fabrication of integrated circuits is the deposition of metal layers which interconnect the various circuit elements that have been formed in earlier process steps. In particular, columns of copper several times higher than the characteristic dimension of the circuit elements was needed. Features with a diameter of a few tenths of a micron and a height of about one micron need to be filled at rates in the half to one micron per minute range. With the successful development of a copper deposition technology meeting these requirements, integrated circuits with simpler designs and higher performance could be economically manufactured.

Several technologies for depositing copper were under development. No single approach had an optimum combination of performance (feature characteristics), cost (deposition rates), and manufacturability (integration with other processes and tool reliability). Chemical vapor deposition, plating, sputtering and ionized-physical vapor deposition (I-PVD) were all candidate technologies. Within this project, the focus was on I-PVD.

DESCRIPTION

The goal was the development of a prototype I-PVD copper deposition tool by a semiconductor process tool company that could be subsequently marketed to the semiconductor industry. A process using electron cyclotron resonance (ECR) plasmas with heated copper vapor source had been developed previously by IBM. However the ECR system used a set of bulky electromagnets and the copper vapor source used resistively-heated molybdenum boats with poor reliability. The technical strategy was to replace the electromagnets with a simple, compact permanent magnet system and to replace the copper vapor source with a sputter-source of copper neutrals.

The CRADA was based on combining Energy Systems' capabilities in plasma source modeling, development, and diagnostics with IBM's complementary skills in process needs and process development, feature evolution modeling, test wafer production, and analysis of processed wafers to develop a copper deposition tool with the needed improvements. Tasks for the CRADA were based on the above skills: Energy Systems performed the plasma source development tasks and processed test articles, IBM specified the process requirements, fabricated test articles, and performed the subsequent analysis. IBM also carried out feature evolution modeling to guide our process development. In addition, IBM played a key role in developing and evolving the commercialization strategy.

BENEFITS TO DOE

DOE Defense Programs (DP) intends to increasingly rely on commercial sources of high performance semiconductors to meet DP needs. The development of copper metallization technology is a key step for the commercial realization of the high performance, low power devices that are needed. This project supported the semiconductor development goals of the DP complex as a whole, and has strengthened the manufacturing and materials processing competencies at Y-12. Many of the benefits from this project will impact the public sector through the continued strength of the U. S. semiconductor industry and the availability of high performance, low cost consumer electronics.

Other DOE programs which will receive benefits from this technology are the ASCI program and the Science Stockpile Stewardship Initiative. Central to the success of ASCI is the availability of high performance integrated circuits (IC) on which the needed advances in computing technology can be based. While copper metallization is but one of many technologies that are required for advanced integrated circuits, the work in this project has contributed to the needed technology base. The Science Stockpile Stewardship Initiative's goals to maintain electronics in weapons will also reap benefits. Reliability is a critical concern for reliable weapons electronic systems. A major failure mechanism of present integrated circuits is the development of "opens" in the internal circuitry of an IC due to electromigration. Copper metallization has the potential for greater electromigration resistance (higher reliability) while at the same time providing increased performance with lower power consumption.

At the more global level, plasma processing of materials to deposit thin films, modify the surface with ion implantation, or remove surface layers is a rapidly growing area of materials processing technology that has been identified in a number of studies, including the National Academy Study on Materials (which helped catalyze the Presidential Initiative on materials research), as a critical national technology. The experience and know-how gained from this project strengthened the DOE position in this important field.

In addition to semiconductors, important applications for DOE include flat panel displays and wear and corrosion resistant coatings. The permanent magnet source, developed in part under this CRADA, has been applied to the problem of manufacturing magneto resistive recording heads for hard disks and is being used by major suppliers around the world.

ECONOMIC IMPACT

The physics and technology developed under this project have helped form a base that is being used for the development of process tools. These tools in turn will contribute to the larger enterprise of integrated circuit manufacturing. Both the tool sales and component manufacturing lie largely in the future. Thus because of the difficulty in assessing the specific "value added" of this research and development and because most products are in the future, it is difficult to assign a specific economic value to the project.

PROJECT STATUS

All key technical milestones were met and several tool suppliers were identified who had an interest in this type of process. However, a commercial relation with a tool supplier was not accomplished due to the existence of competing cross-licensed patents and early competitive work by the respective suppliers. As a result, the project was terminated in an orderly manner. Nevertheless, the overall goal of contributing to the development of a U. S. capability in this area has been met, as the research and development in the project have contributed to the development of tools which will achieve the semiconductor manufacturing goals.

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PROJECT EXAMPLES
No project examples are available.

TECHNOLOGY COMMERCIALIZATION
A number of production tool vendors initiated research and development programs and now have concrete plans for production tools. Although there is little chance for direct licensing of the work performed under this CRADA, the strategy suggested by IBM for this CRADA of rapid publication and results sharing has played an important role in encouraging development of the technology and has helped put U.S. manufacturers in an excellent position to take the lead in production of the next generation of I-PVD based metallization tools.

Several of these large tool companies have definite product plans for an I-PVD tool. In fact, one has already identified I-PVD as their only viable option for critical dimensions (down to 0.1 micron), for high-aspect ratio plug fill (7:1), for low temperature, and for metallization materials (TiN, AlCu). They now have working tools for their one of their systems and plan to start shipping beta-site tools in August 1996. They have already performed test runs for other integrated circuit manufacturers and are going full-steam towards I-PVD as their primary technology for about 2-3 years out. I-PVD is also being actively considered by several equipment manufacturers for feature lining.

Thus, the work of IBM and ORNL, including work performed as part of this CRADA, has played an important role in the decision of the semiconductor industry to change its course and move towards the use of I-PVD. In addition, innovations used as part of the system design have been refined and made more attractive to industry for use in research systems

The I-PVD system developed as part of this CRADA shows promise for a variety of other applications for which sputtering has been previously used, such as synthesis of tribological coatings. Boron oxide coatings, which were developed at ORNL and show promise for tribological applications, are well suited for scale up using the technology developed as part of this CRADA. Another possible commercial application is the development of a replacement for hard chrome.

Attachments:
Figure 1 -- Launcher assembly for the copper-metallization plasma source. Shown are (from bottom to top): replaceable "sheet metal" microwave launcher; helical flex vacuum gasket; quartz vacuum window; window flange; and launcher housing.

Figure 2 -- View of the permanent magnet plasma source from below as illuminated by plasma light. The periodic "spokes" result from the radial multipole confinement magnets. The rectangular aperture visible in the center of the photograph is the exit of the microwave launcher which was shown in the previous photograph.

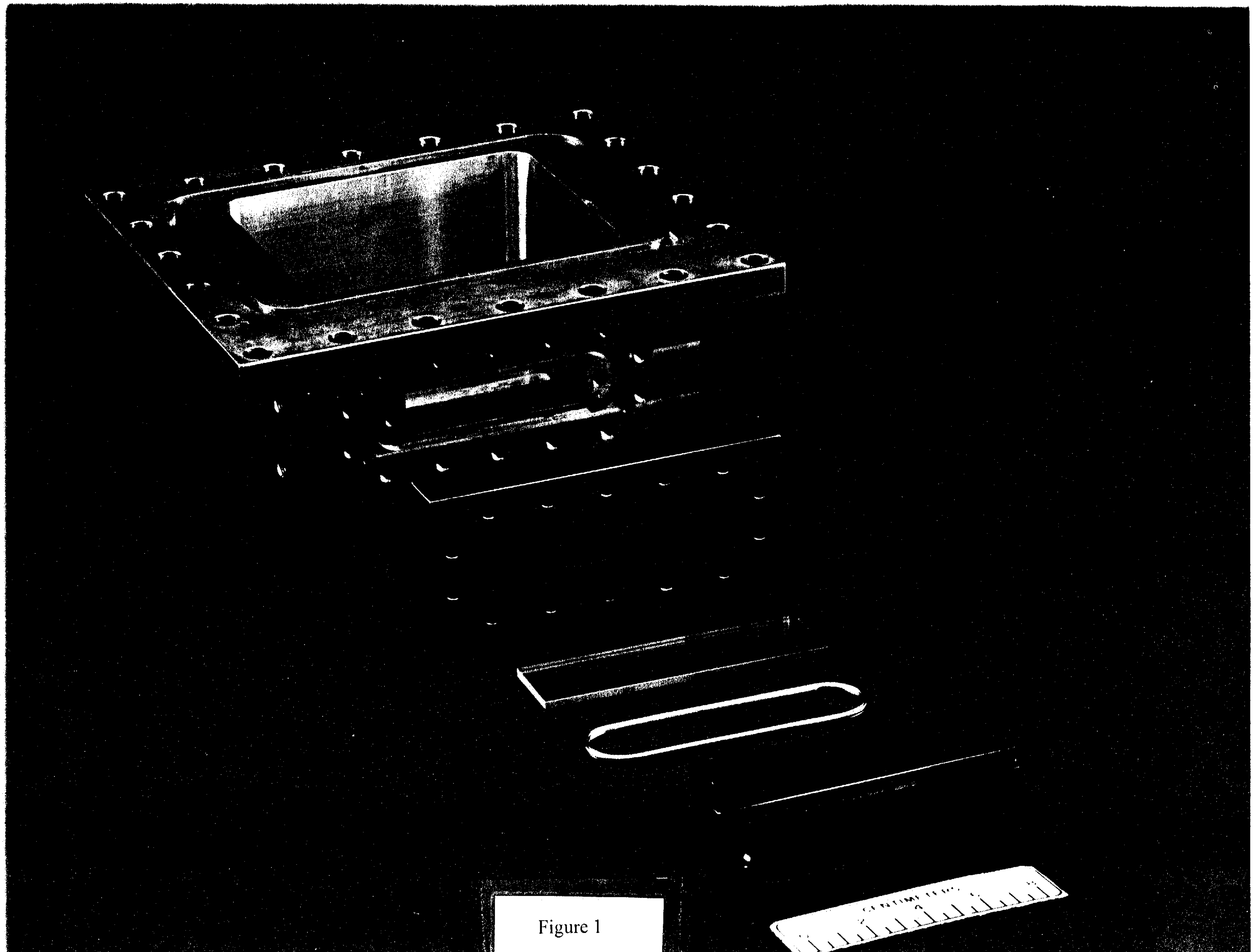

Figure 1

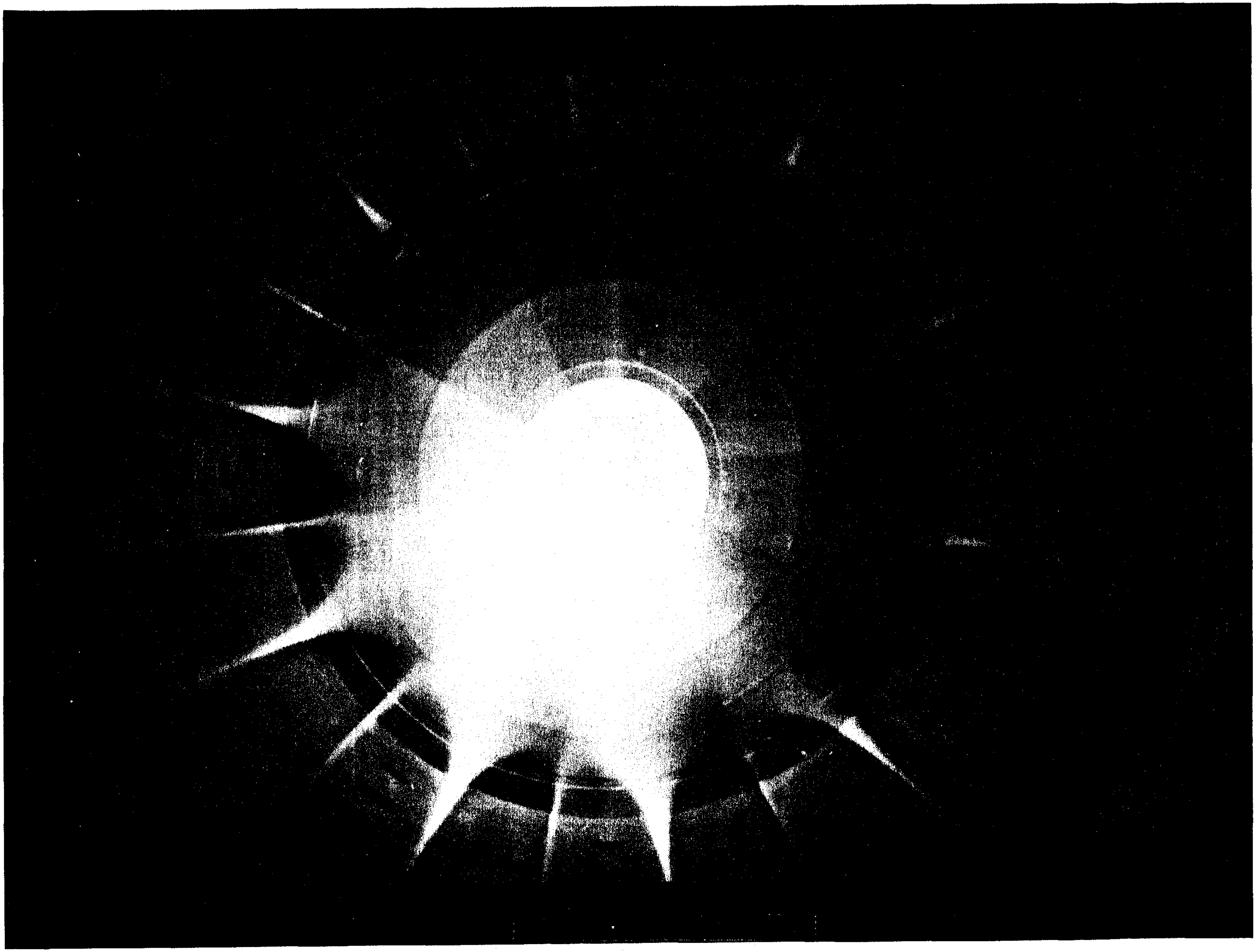

Figure 2

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