Developing a prototype for microwave assisted bending of fused silica

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Abstract— **Quartz glass is an important material in the semiconductor industry. Reactor chambers for epitaxy are manufactured from bent glass plates. Bending a quartz glass plate is a process that is still done by hand, with workers heating the bending edge with oxyfuel torches. The annealing colour is used to decide when the forming temperature is reached. The glass is then bent with the help its own weight.**

This process is still cumbersome, requires a lot of skill and experience and requires three workers. One approach to simplify this process is the use of microwaves. At room temperature the microwaves transmit almost completely through the glass. At a temperature of about 1400°C, however, the waves are largely absorbed. This means that the residual heat can be introduced specifically at the bending edge.

To heat the glass plate to 1400°C hydrogen-oxygen burners are used, which are directed towards the bending edge. When the glass is warm enough, it is placed over the microwave emitter. The microwave emitter then heats the glass to the forming temperature.

Keywords—microwave heating; fused silica; quartz glass

I. INTRODUCTION (*HEADING 1*)

Quartz glass is a material that is used today in a wide variety of applications. Among others in the field of epitaxy in semiconductor technology. For this purpose, bent quartz glass plates are welded to form a reactor chamber. The bending of these glass plates is a work step that is still done by hand today. For this purpose, the plate is heated simultaneously from above and below by two workers with two hydrogen-oxygen burners each by periodic movements along the bending edge (see figure 1). A third working force stands at the front side of the quartz glass plate and supports it with two metal paddles. This paddle recognizes the correct time for bending the plate purely by the visual impression of the glowing bending edge. To do this, he removes the paddles from the underside of the plate and uses them to apply the necessary force to bend the glass plate at a 90° angle in addition to the weight. To ensure the angle is correct, the glass rests on a graphite block that is optimized for the required bending radius and angle. The execution of this work step therefore requires the capacity of three workers with a time expenditure of about five minutes per glass sheet [1].

Figure 1: Manual bending of quartz glass [1]

This process could be automated by using the absorption capacity of quartz glass at high temperatures against microwaves. For this purpose, the glass must be heated to a temperature of 1470°C so that β-cristobalites are formed in the microstructure (see figure 2). These have the required absorptivity [2].

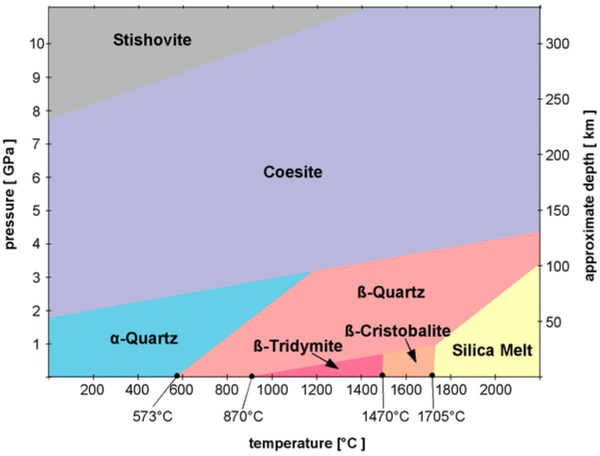
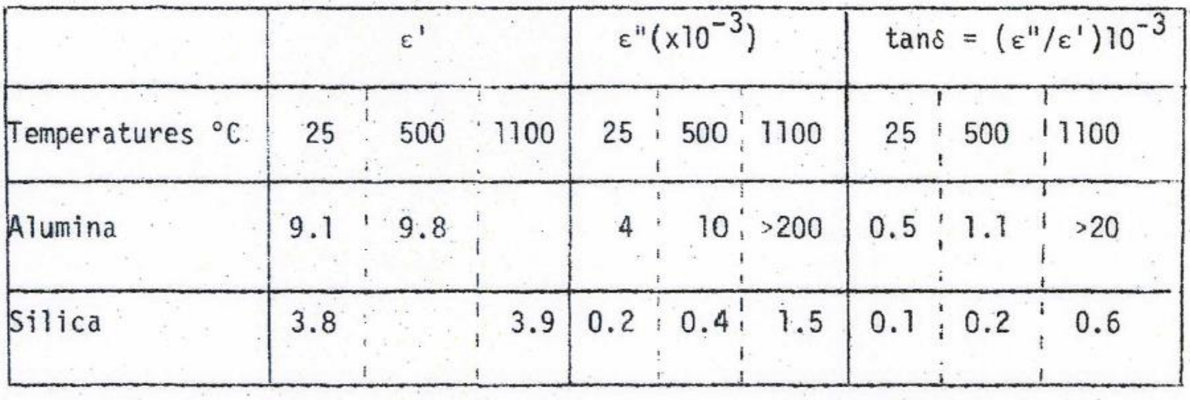


Figure 2: Phase diagram of fused silica [2]



	ε'			$\varepsilon''(\times 10^{-3})$			$\tan\delta = (\varepsilon''/\varepsilon')10^{-3}$		
Temperatures °C	25	500	1100	25	500	1100	25	500	1100
Alumina	9.1	9.8		4	10	>200	0.5	1.1	>20
Silica	3.8		3.9	0.2	0.4	1.5	0.1	0.2	0.6

Figure 3: Dielectric coefficients for alumina and quartz glass at rising temperature [5]

Dielectrics, which also include quartz glass, do not have any dipoles in their structure which could be set in oscillation by microwaves, but nevertheless a temperature generation is achieved by irradiation. If the dielectric is penetrated by an alternating electromagnetic field, both the nucleus and the electron path of the atoms of the dielectric vibrate.

The oscillation of the atomic nucleus is to be regarded as small compared to the oscillation of the electron orbit and can therefore be neglected. The oscillating electron orbit around the nucleus results in a dipole character of the atoms. The now existing dipole is aligned with the applied field, which continuously changes with the frequency of the microwave generator. Friction effects occur in the material, which results in the desired temperature generation [3, 4].

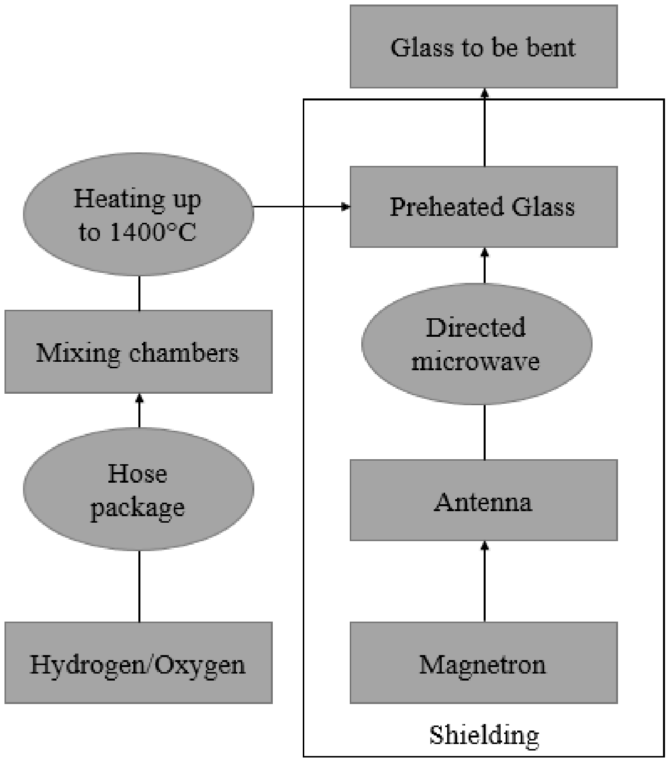


Figure 4: Schematic of the prototype

The dielectric coefficient of a material indicates how quickly the temperature is raised by microwave irradiation. In the case of quartz glass, this is about 4 at room temperature, but increases in proportion to the temperature of the glass (see figure 3). According to this, autogenous preheating is essential to reach the melting point [5]

II. SETUP

For microwaves to couple into the glass, it needs a temperature of about 1400°C. This temperature can only be achieved by autogenous preheating, which means that the process is a two-stage one. Once the glass has been heated by line burners, it can be brought into position by a carriage above the antenna which directs the microwave radiation. The antenna is located in a cage made of perforated aluminium. This acts as an optical grid and prevents the microwave from leaving the shielding. This ensures the safety of the user (see figure 4).

The fuel gas for the preheating process is hydrogen, as this gas does not form adsorbates on the surface of the glass. The microwave with a frequency of 2.45 GHz is generated by a magnetron with a maximum power of 1.25kW. This is fed into a waveguide by a circulator. At the end of this waveguide there is a movable wall which reflects the wave. The wave is coupled out through an opening on the upper side of the guide. The wave is directed via a rod antenna and a funnel. Reflections within the hollow waveguide are prevented from damaging the magnetron by the circulator. Instead, they are directed to an electromagnetic load equipped with a measuring probe. Here the power of the wave is measured and absorbed.

III. RESULTS

A. Load within the shielding

The setup is investigated with respect to its properties of reflection within the waveguide as well as its transient response when the magnetron is started.

Figure 5 shows the reflectance values with a load in the system and without load. The load represents a metallic conductor which is not earthed. This conductor absorbs the radiation and converts it into heat. It can be seen what influence a load has on the reflected power in the hollow waveguide. If the wave cannot be absorbed at a point within the shielding, the probe is exposed to a much higher power. A transient response of the magnetron can also be observed. Both, with and without load, a decrease of the reflection with increasing time is evident. This can be explained by the heating of the magnetron. The magnetron is designed to function at an operating temperature which is only given after a certain operating time.

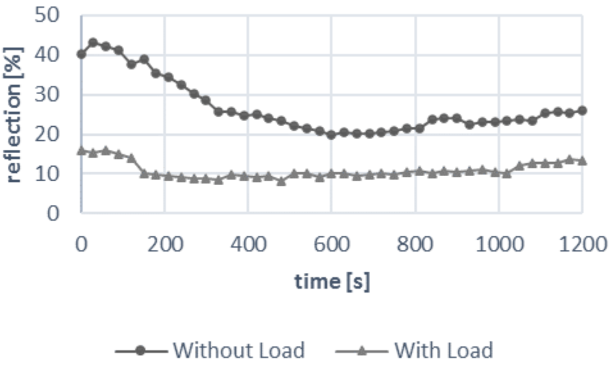


Figure 5: Reflection with and without a load within the shielding

B. *Matchbox Position*

The movable wall at the end of the waveguide is used to tune the wave to allow the highest possible wave decoupling. The aim here is to achieve constructive interference at the location of the antenna. It is investigated how the adjustment of the wall changes the reflection and what influence the position of the load above the antenna has. In this test the load is a water reservoir which is placed directly above the antenna.

Figure 6 shows the tuning behaviour of the movable wall. The best possible setting depends on the position of the load. The graph shows a significant difference between a load placed centrally above the antenna compared to the same load placed at the edge of the hopper. Therefore, no universally applicable setting is possible. This must be done separately for each case.

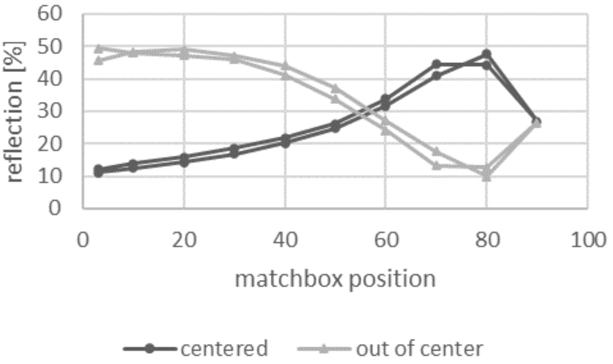


Figure 6: Reflection values for different initial settings

C. *Antenna*

The aim of the prototype is to bend quartz glass. For this purpose, it requires a sufficiently high preheating temperature and the highest possible power density at the bending edge. The funnel directing the wave serves this purpose.

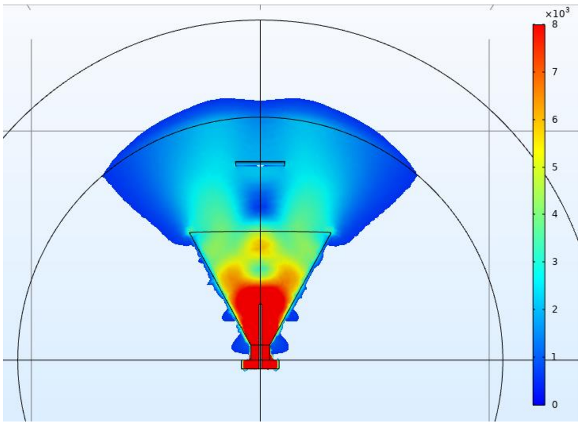


Figure 7: Simulation of the initial cone funnel

The simulation of the output funnel shows an annular maximum at the edges. In the best case, however, the maximum is concentrated linearly on the bending edge. In order to achieve a sufficiently high power density for test purposes, a horn is manufactured which, although it has no radiation characteristic, forms a maximum directly at the horn mouth. The glass can thus be placed on the horn mouth, heated manually, and exposed to the maximum radiation.

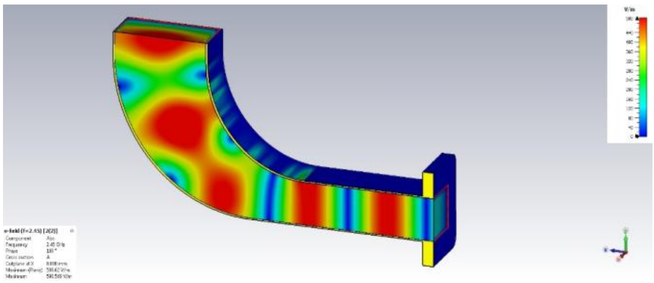


Figure 8: Fan horn antenna (Source: Muegge Gmbh]

The simulation shows the propagation of the wave in the antenna and the maximum at the horn mouth. This antenna also replaces the movable wall at the end of the waveguide, so that a tuning, which is strongly dependent on the load, is no longer necessary.

How much power can be injected at the end of the horn is tested using water as an example. 150ml of water is placed in the middle of the antenna and heated with 100 percent of the magnetron power. The heating of the water is recorded by a temperature sensor.

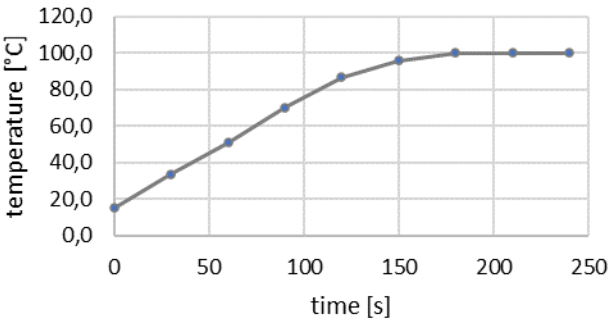


Figure 9: Water temperature at 100% microwave power

From the result of the test, the power injected into the water can be calculated as follows.

$$P = \frac{m * c * \Delta T}{w * t} \qquad (1)$$

With:

m: mass

c: Thermal capacity

ΔT: temperature difference

w: Efficiency

t: time

If the efficiency is assumed to be 0.75, the following result is obtained.

$$P = \frac{0.15kg * 4181 \frac{J}{kg * °C} * (100°C - 15°C)}{0.75 * 180s} = 395W \qquad (2)$$

The water was thus heated with 395W at a theoretical power of 1250W produced by the generator. The difference between these values can be explained by losses that occur at joints and the radiation that is not entirely concentrated on the water. In addition, the power of the generator is to be doubted by the factory. Due to the age of the machine, it is highly likely that it will not be able to generate full power.

For production reasons, the prototype is not able to heat preheated quartz glass at the end of the project, so that no results with glass are available. However, this function can be made possible later by further adaptations to the system.

IV. CONCLUSION

The prototype is capable of achieving a high power density in a relatively small area through various adjustments. Since the modification of the system has rendered the function of the line burners ineffective, experiments with quartz glass are not possible. If the prototype is further adjusted to allow preheating, experiments on quartz glass can be carried out with the now higher power and possibly the thesis can be verified that a glass plate can be heated sufficiently by microwaves at its bending edge to achieve sufficient deformability to bend this plate.

[1] S. Menzel, “Vorhabensbeschreibung: Mikrowellenunterstütztes Biegen von Quarzglas für die Mikroystemtechnik,”. Technologie Anwender Zentrum Spiegelau, 2018

[2] S. Schorn, www.mineralienatlas.de [Online]. Available: https://www.mineralienatlas.de/lexikon/index.php/Mineralienportrait/Quarz/Modifikationen%20des%20Siliziumdioxids. [Access on 18 07 2019]

[3] R. J. Meredith; “Engineers Handbook of industrial Microwave Heating,” London; United Kingdom: The Institution of Electrical Engineers, 1998, pp. 19ff.

[4] A. C. Metaxas and R. J. Meredith; “Industrial Microwave Heating,” United Kingdom: Peter Peregrinus LTD, 1983

[5] J. A. Berteaud and J. C. Badott, “High Temperature Microwave Heating in Refractory Materials,” Canada: Journal of Microwave Power; 1976, pp. 315-320